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DEVELOPMENT DOCUMENT FOR EFFLUENT LIMITATIONS GUIDELINES AND NEW SOURCE PERFORMANCE STANDARDS FOR THE BAUXITE REFINING SUBCATEGORY OF THE ALUMINUM SEGMENT OF THE NONFERROUS METALS MANUFACTURING POINT SOURCE CATEGORY

ENVIRONMENTAL PROTECTION AGENCY

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Effluent limitations guidelines are set forth for the degree of effluent reduction attainable through the application of the "Best Practicable Control Technology Currently Available" and the "Best Available Technology Economically Achievable" which must be achieved by existing point sources by July 1, 1977 and July 1, 1983, respectively. The "Standards of Performance for New Sources" set forth a degree of effluent reduction which is achievable through the application of the best available demonstrated control technology processes, operating methods or other alternatives.

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DEVELOPMENT DOCUMENT for EFFLUENT LIMITATIONS GUIDELINES and NEW SOURCE PERFORMANCE STANDARDS for the BAUXITE REFINING SUBCATEGORY of the ALUMINUM SEGMENT of the NONFERROUS METALS MANUFACTURING POINT SOURCE CATEGORY

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ABSTRACT

This document presents the findings of a study of the bauxite refining industry by the Environmental Protection Agency for the purpose of developing effluent limitation guidelines and standards of performance for the industry, to implement Sections 304, 306, and 307 of the Federal Water Pollution Control Act as amended.

Effluent limitations guidelines contained herein for the bauxite refining industry set forth the degree of effluent reduction attainable through the application of the best practicable control technology currently available, and the application of the best available technology economically achievable, which must be achieved by existing point sources by July 1, 1977, and July 1, 1983, respectively. The standards of performance for new sources contained herein set forth the degree of effluent reduction attainable through the application of the best available demonstrated control technology, processes, operating methods, or other alternatives.

The major process waste from bauxite refining is the red mud residue remaining after extraction of the alumina. Thousands of tons per day are produced by the typical refinery. Total impoundment of process wastes was determined to represent the best practicable control technology currently available for existing point sources. No discharge of process waste water pollutants to navigable waters is the effluent limitation to be achieved by existing point sources by July 1, 1977, and as the standard of performance for new sources.

Supportive data and rationale for development of the effluent limitations guidelines and standards of performance are contained in this report.

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SECTION I

CONCLUSIONS

For the purpose of establishing effluent limitations guidelines and standards of performance, the aluminum segment of the nonferrous metals manufacturing point source category was divided into three subcategories. This report deals with the bauxite refining subcategory. Consideration of the factors of age and size of plant, processes employed, geographical location, wastes generated, and waste water treatment and control techniques employed support this conclusion. The similarities of the wastes produced by bauxite refining operations and the control and treatment techniques available to reduce the discharge of pollutants further substantiate the treatment of bauxite refining as a single subcategory.

It is concluded that the best practicable control technology currently available consists of techniques including impoundment (controlled disposal on land), the management of process waters by methods dependent on the impoundment capability and the evaporative capability inherent in the bauxite refining process as currently practiced, and various measures applied to individual waste streams including neutralization and impoundment to eliminate the discharge of process waste water pollutants to navigable waters. Recycle of water contained in the impoundment area should be practiced to the maximum extent possible.

It is further concluded that the current technology of impoundment to control the major process waste (red mud) allows the control of other wastes by use of the same impoundment facilities with or without prior treatment such as neutralization.

It is also concluded that the best available technology economically achievable applicable to existing sources and the best available demonstrated control technology, processes, operating methods or other alternatives applicable to new sources and equivalent to the best practicable control technology currently available.

SECTION II

RECOMMENDATIONS

The effluent limitations and standards of performance for the bauxite refining subcategory are no discharge of process waste water pollutants into navigable waters.

The effluent limitations are considered achievable by all existing sources by July 1, 1977, inasmuch as two plants currently achieve the effluent limitations. The limitations are based on the application of control and treatment technology meeting the criteria for best practicable control technology currently available, best available technology economically achievable, and the best available demonstrated control technology, processes, operating methods, or other alternatives.

The technologies on which such effluent limitations and standards are based consist of impoundment, in the form of a red mud lake, of the major solid waste from the bauxite refining processes, and the management of process streams and waste waters using the red mud lake, other impoundment lakes, and/or the evaporative capability present in the bauxite refining operation. Thus, a closed cycle system with reuse of water within the system is achieved. The technologies identified also include the treatment of smaller associated waste water streams by such means as neutralization, with subsequent disposal of neutralization sludges to the solid waste impoundment facility and the control of remaining waste waters by impoundment, evaporation, or recycle within the plant facility. Treatment may involve, for example, neutralization before impoundment, as for spent cleaning acid; or the treatment may involve evaporative cooling, as for barometric condenser effluents. In such cases, the treated effluents are contained within the cycle.

These identified waste water control technologies are directly related to the characteristics of the bauxite refining process, which, as currently practiced, inherently involves control of the amount of water in relatively large volumes of process streams and always contains evaporative capacity for control of the composition of process streams and product drying.

Under certain conditions, the discharge of excessive accumulations of rainfall may be allowed from point sources as an exception to the above limitations and practices. This exception is based on the recognition that most bauxite refining plants occupy large areas, and are located in climatic regions where short-term (i.e., hours or days) high rainfalls occur. Further, annual variations in rainfall may exceed the capacity of even reasonably designed impoundment facilities.

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SECTION III

INTRODUCTION

Purpose and Authority

Section 301(b) of the Act requires the achievement by not later than July 1, 1977, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best practicable control technology currently available as defined by the Administrator pursuant to Section 304(b) of the Act.

Section 301(b) also requires the acievement by not later than July 1, 1983, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best available technology economically achievable which will result in reasonable further progress toward the goal of eliminating the discharge of all pollutants, as determined in accordance with regulations issued by the Administrator pursuant to Section 304(b) to the Act.

Section 306 of the Act requires the achievement by new sources of a Federal standard of performance providing for the control of the discharge of pollutants which reflects the greatest degree of effluent reduction which the Administrator determines to be achievable through the application of the best available demonstrated control technology, processes, operating methods, or other alternatives, including, where practicable, a standard permitting no discharge of pollutants.

Section 304(b) of the Act requires the Administrator to publish within one year of enactment of the Act, regulations providing guidelines for effluent limitations setting forth the degree of effluent reduction attainable through the application of the best practicable control technology currently available and the degree of effluent reduction attainable through the application of the best control measures and practices achievable, including treatment techniques, process and procedure innovations, operation methods and other alternatives. The regulations contained herein set forth effluent limitations guidelines pursuant to Section 304(b) of the Act for the bauxite refining subcategory of the nonferrous metals category.

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Summary of Methods Used for Development of the Effluent Limitations Guidelines and Standards of Performance

The effluent limitations guidelines and standards of performance contained herein were developed in the following manner. General information was obtained on all domestic bauxite plants in the continental U.S. by means of a questionnaire.

Data for the development of effluent limitations guidelines were based largely on site visits and interviews at the eight continental U.S. plants, supplemented by published technical and trade literature, telephone interviews, EPA technical reports, and meetings with EPA personnel.

The industry was first examined for purposes of determining whether separate limitations and standards are appropriate for different subsegments within a point source category. Possible further subcategorization was considered, based upon raw materials used, processes employed, product produced, geographic location, size, and age of plants, wastes generated, and other factors, as discussed in Section IV.

From the on-site inspections and the questionnaire responses, flow diagrams, and information on water management practices, control and treatment methods, equipment and costs were acquired.

From these data, the differences in raw waste characteristics were identified. This included:

1) Analysis of the source and volume of water used in the process, the sources of waste and waste water in the plant, and type and quantity of constituents in the waste waters, as discussed in Section V.

2) Identification of those constituents, discussed in Section VI, which are characteristic of the industry and are present in significant quantities. These pollutants are subject to effluent limitations guidelines and standards of performance.

The information, as outlined above, was then evaluated in order to determine what levels of technology constituted the best practicable control technology currently available, best available technology economically achievable, and the best available demonstrated control technology processes, operating methods and other alternatives. In identifying such technologies, various factors were considered. These included the total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application, the facilities involved, the process employed, the engineering aspects of the application of various types of control techniques, process changes, nonwater quality environmental impact (including energy requirements) and other factors, as discussed in Sections IX, X, and XI.

In view of the small number of plants and the geographical concentration of the industry, it was possible to visit and acquire detailed data from all 8 of the bauxite refineries in the continental United States. Only the refinery in the Virgin Islands was not included in the industry sample, so that 90 percent of the plants, and a larger percentage of production, was included in the survey sample.

General Description of the Industry

This document applies to the bauxite refining industry, Standard Industrial Classification (SIC) 2819 (alumina only).

Although the manufacture of aluminum metal dates back to the simultaneous discovery by Hall and Heroult of the electrolytic reduction process, the rapid growth of the industy began only during World War II. Almost overnight, the demands for this light metal for aircraft created the large industry of today. Because of this growth pattern, aluminum is one of the youngest metal industries, and very few plants, either primary aluminum or bauxite refining, are more than 30 years old.

Bauxite is the principal ore of aluminum and the only one used commercially in the United States. Aluminum is a unique metal in that all of its purification is accomplished in the bauxite refining step; none occurs in the subsequent reduction to metal. Thus, the purification requirements in producing refined alumina (Al_2O_3) from the raw ore are strict. Bauxite consists of aluminum oxide, more or less hydrated and containing various impurities, such as iron oxide, aluminum silicate, titanium dioxide, quartz, and compounds of phosphorus and vanadium. Bauxite ores vary in characteristics from stony materials to soft clays. In general the term bauxite applies to weathered deposits from which substances other than alumina have been leached to leave a sufficient alumina content to make the deposit profitably workable. The process chemistry of alumina refining is basically quite simple, and the classic Bayer process is universally used in the United States. In this process the impure alumina in the bauxite is dissolved in a hot, strong alkali solution, generally $NaOH$, to form sodium aluminate. Upon dilution and cooling the sodium aluminate hydrolyzes, forming a precipitate of aluminum hydroxide which is filtered and calcined to alumina. The operations employed are those typical of very large scale hydrometallurgical operations, conducted in essentially a closed circuit, and economically possible only with maximum recovery of heat and a near quantitative recovery of reagents.

Bauxite refining is carried on in the United States only by primary aluminum producers. The majority are integrated back to the bauxite refinery or to the mine. Bauxite refining is characteristically conducted in very large scale installations. There are only nine U.S. bauxite refineries, owned by five primary aluminum producers. Alumina capacities, shown in Table 1, vary from 325,000 to 1,3000,000 metric tons (360,000 to 1,440,000

TABLE 1. OPERATING COMPANIES, LOCATIONS, CAPACITIES, AND DATE OF OPERATION OF U.S. BAUXITE REFINING PLANTS

Company	Plant Location	Date of Commercial Operation	Approximate Plant Capacity, tons alumina		
			Metric Tons/Day	Short Tons/Day	Metric Tons/Year(a)
Aluminum Company of America	Mobile, Alabama	1938	2,270	2,500	820,000
	Pt. Comfort, Texas	1959	3,200	3,500	1,150,000
	Bauxite, Arkansas	1952	900	1,000	325,000
Kaiser Aluminum and Chemical Corp.	Baton Rouge, Louisiana	1942	2,800	3,100	1,010,000
	Gramercy, Louisiana	1960	2,400	2,650	865,000
Reynolds Metals Co.	Corpus Christi, Texas	1953	3,600	4,000	1,300,000
	Hurricane Creek, Arkansas	1942	2,100	2,300	755,000
Ormet Corporation	Burnside, Louisiana	1958	1,550	1,700	560,000
Martin-Marietta Aluminum Co.	St. Croix, Virgin Islands	1967	900	1,000	325,000
	Total U.S. Capacity		19,720	21,750	7,200,000

(a) Basis 360 day/year operation (98.6% of capacity).

short tons) per year. The locations of the eight refineries in the continental United States are shown in Figure 1.

Alumina production capacity is in reasonable balance with consumption, and the period of explosive growth of the industry appears to have subsided (see Table 2). Over the last several years, the industry has operated substantially below capacity. The next round of growth is judged to be some years away and industry consensus appears to be that no large additions to bauxite refining capacity in the form of new, grass-roots plants are anticipated over the next several years. Future expansion is more likely to be in the form of incremental expansions and additions to existing plants.

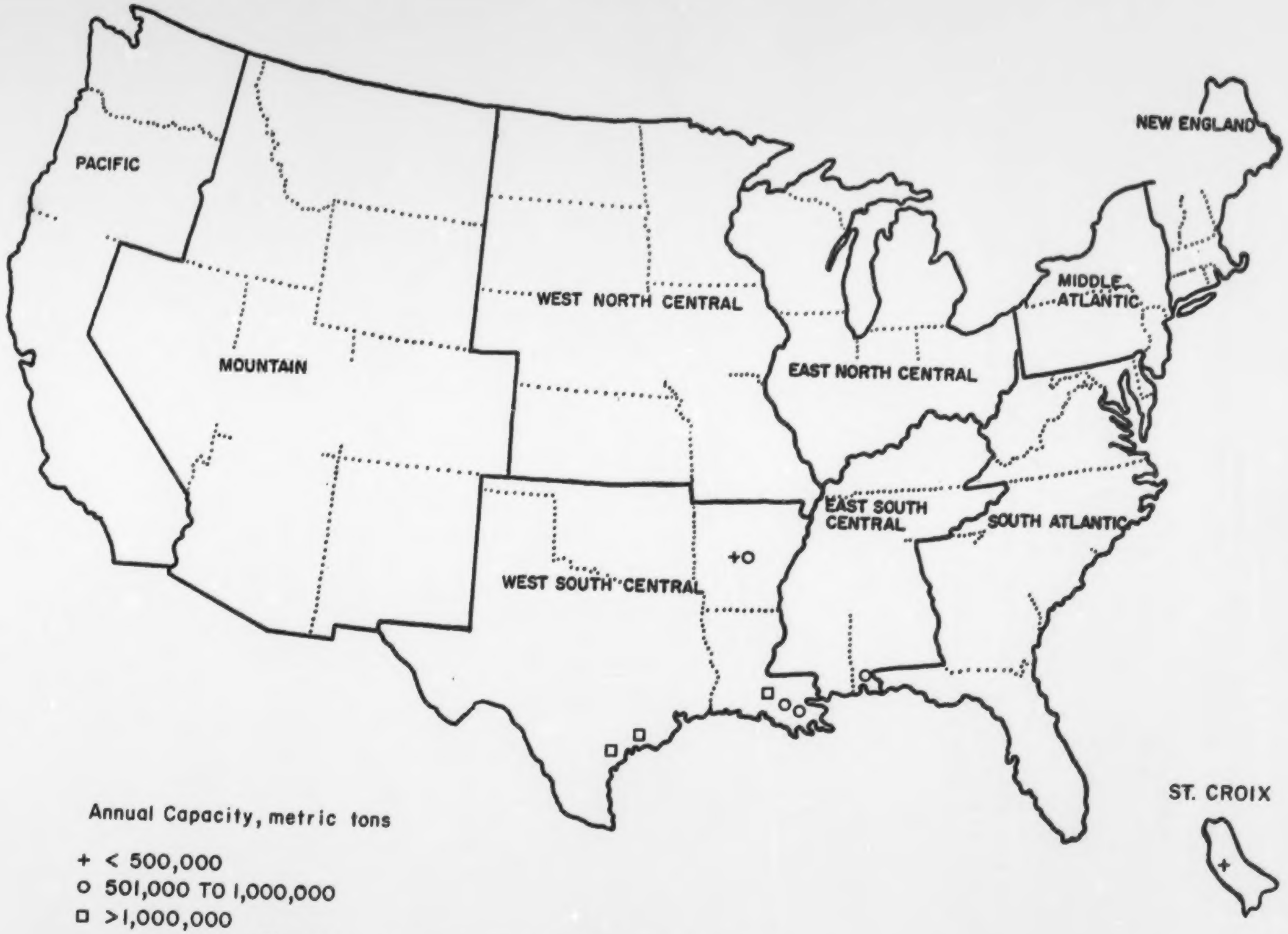
PACIFIC
MOUNTAIN
WEST NORTH CENTRAL
EAST NORTH CENTRAL
NEW ENGLAND
MIDDLE ATLANTIC
SOUTH ATLANTIC
EAST SOUTH CENTRAL
WEST SOUTH CENTRAL
ST. CROIX
Annual Capacity, metric tons
+ < 500,000
○ 501,000 TO 1,000,000
□ >1,000,000

Figure 1. Location of alumina refining plants in the U.S.

TABLE 2. PRODUCTION OF PRIMARY ALUMINUM IN THE UNITED STATES

Year	Production, short tons	Annual Increase Short Tons	Annual Increase Percent
1950	718,600	115,100	19.1
1951	836,900	118,300	16.5
1952	937,300	100,400	12.0
1953	1,252,000	314,600	33.6
1954	1,460,600	208,600	16.6
1955	1,565,700	105,100	7.2
1956	1,679,000	113,300	7.2
1957	1,647,700	31,300(a)	1.9(a)
1958	1,565,600	83,100(a)	4.9(a)
1959	1,954,100	388,500	24.8
1960	2,014,500	60,400	3.1
1961	1,903,700	110,800(a)	5.5(a)
1962	2,117,900	214,200	11.3
1963	2,312,500	194,600	9.1
1964	2,552,700	240,200	10.4
1965	2,754,500	201,800	7.9
1966	2,968,400	213,900	7.7
1967	3,269,200	300,800	10.3
1968	3,255,000	14,800(a)	0.4(a)
1969	3,793,000	538,000	16.5
1970	3,976,100	183,100	4.8
1971	3,905,000	70,900(a)	1.8(a)
1972	4,120,000	225,000	5.4

(a) Decrease.

Source: Metal Statistics, 1972.(1)

SECTION IV

INDUSTRY CATEGORIZATION

Introduction

In developing effluent limitations guidelines and new source performance standards for a given industry, a judgment must be made as to whether these regulations can be uniformly and equitably applied to the entire industry, or whether sufficient differences exist to warrant the establishment of additional subcategories. The factors considered in determining whether such subcategories are justified for bauxite refining were:

(1) Manufacturing process.
(2) Raw materials.
(3) Products produced.
(4) Wastes generated.
(5) Plant size and age.
(6) Plant location.
(7) Air pollution control equipment.

As a result of a study of the literature, plant inspections, and communications with the industry, it was concluded that the bauxite refining industry should be considered as a single subcategory.

Factors Considered

Manufacturing Process

Process Description. The refining of alumina from bauxite is accomplished by either of two processes, the Bayer process or the combination process. The combination process is a variation of the Bayer process in that the solid residue is retreated. The Bayer process has been in use since about 1895, and is now a mature technology.

Bayer Process. In the Bayer process, the hydrated alumina in the bauxite is converted to a soluble salt, sodium aluminate, by reaction with either sodium hydroxide or a combination of lime and sodium carbonate to accomplish the following net reaction:

(monohydrate) $Al_2O_3 \cdot H_2O + 2NaOH \longrightarrow 2NaAlO_2 + 2H_2O$

(trihydrate) $Al_2O_3 \cdot 3H_2O + 2NaOH \longrightarrow 2NaAlO_2 + 4H_2O$.

In practice this reaction is accomplished by mixing the ground ore with caustic solution in large iron mixing tanks. The mixture is fed into pressure vessels or autoclaves, and heat and pressure are developed by either steam heating of jacketed autoclaves or, more generally, by direct injection of live steam.

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Conditions must be varied to suit the bauxite ore composition, but may be indicated as follows:

monohydrate forms - a solution containing 200 to 300 g/l of Na_2O and temperature of 200 to 250°C at pressures as high as 35 atmospheres (500 psi).

trihydrate forms - a solution containing 100 to 150 g/l of Na_2O and temperatures of 120 to 170°C at 3.40 to 4.75 atmospheres (50 to 70psi) pressure.

Most bauxite ores contain different proportions of the monohydrate and trihydrate forms, and operating conditions are adjusted to obtain optimum processing. The greater portion of bauxites processed in the United States are predominantly of the trihydrate form, which permits the use of the lower concentrations, temperatures, and pressures. There are minor differences in severity of processing conditions between refiners, which are described later, but these differences do not significantly influence aqueous process effluents.

The bauxite ore, if imported, is dried before shipment to eliminate excess moisture; locally mined ore, as in Arkansas, is used as received, although it is stored under cover in a blending building before use. Prior to leaching, bauxite ore is ground. An exception is Jamaican ore, which has a particle size so small that grinding prior to leaching is unnecessary.

The product of the above digestion process is a slurry containing $NaAlO_2$ in aqueous solution and undissolved solids. The insoluble residue remaining after the attack is commonly known as red mud, and contains the iron oxides from the bauxite, as well as some sodium aluminosilicate, titanium dioxide (TiO_2), and various other secondary impurities.

Red mud from various bauxites has different characteristics. These characteristics produce varying disposal problems at different refineries. For example, the yield of red mud residue from Surinam bauxite is low (approximately 1/3 ton per ton of alumina product), and the mud is amenable to filtration and effective washing on a filter. Thus, the final residue is relatively easy to handle and disposal area requirements are moderate. On the other hand, red mud from Jamaican bauxite is produced in much greater yield, (approximately 1 ton per ton of alumina), due to its larger content of contaminants. Its physical characteristics are such that filtration may be uneconomic at this time, and the muds are separated and washed by as many as seven stages of countercurrent decantation. The caustic values recovered by the washing are concentrated by evaporation and returned to the process.

The red mud may be moved as a waterborne slurry to a waste area, known as the red mud lake, and not further processed. In the past, and still occurring at some domestic refineries, the red mud has been discharged to a river. Under an existing Federal consent decree, these discharges will soon stop. Jamaican red mud also has poor settling properties, so that its disposal on land could pose serious problems. As noted in a later discussion, a solution to this problem has recently been developed to the point of commercial application.

A generalized schematic flowsheet of the Bayer process is shown in Figure 2. As described above, the separation and washing of the red mud residue may be accomplished by filtration or countercurrent decantation, depending on its handling characteristics. Another feature of the process, which is a relatively large energy consumer, is the maximization of heat recovery; heat exchangers are a major feature of the process flowsheet. All possible caustic values are recovered from the red mud residues for return to the digestion step. This introduces a problem common to many closed extractive circuits, namely, buildup of soluble contaminants. Excessive concentrations of contaminants in the sodium aluminate liquor can interfere with alumina precipitation, and control measures may be required. Some contaminants can be eliminated by contact of the spent liquor with the red mud residues in a holding tank. Another approach is to pass a portion of the mother liquor through a salting-out evaporation step.

Combination Process. In the combination process, applied to high-silica bauxites such as those from Arkansas, the red mud residue is treated to extract additional amounts of the alumina and to recover sodium values. This additional extraction step is accomplished by mixing the red mud with limestone (effectively $CaCO_3$) and sodium carbonate, and then sintering this mixture at 1100 to 1200°C. The important reactions are the conversion of silica to calcium silicate and residual alumina to sodium aluminate. The sintered products are leached to produce additional sodium aluminate solution, which is either filtered and added to the main stream for precipitation or is precipated separately. The residual solids (brown mud) are slurried to a waste lake. A generalized flowsheet of the combination process is shown in Figure 3. Although omitted for simplicity, the analogous use of heat exchangers and condensates shown in Figure 2 is used.

One feature of the combination process is that lime and soda ash may substitute totally for caustic soda as the starting reagent, utilizing the familiar reaction:

$$Ca(OH)_2 + Na_2CO_3 \dashrightarrow 2NaOH + CaCO_3.$$

From either of the alternative processes, purified sodium aluminate solution is passed through heat exchangers and cooled to 50 to 60°C prior to being discharged into large precipitation vessels. By the addition of seed material and by careful control of composition and controlled agitation, alumina trihydrate is precipitated in a controlled form, amenable to easy separation

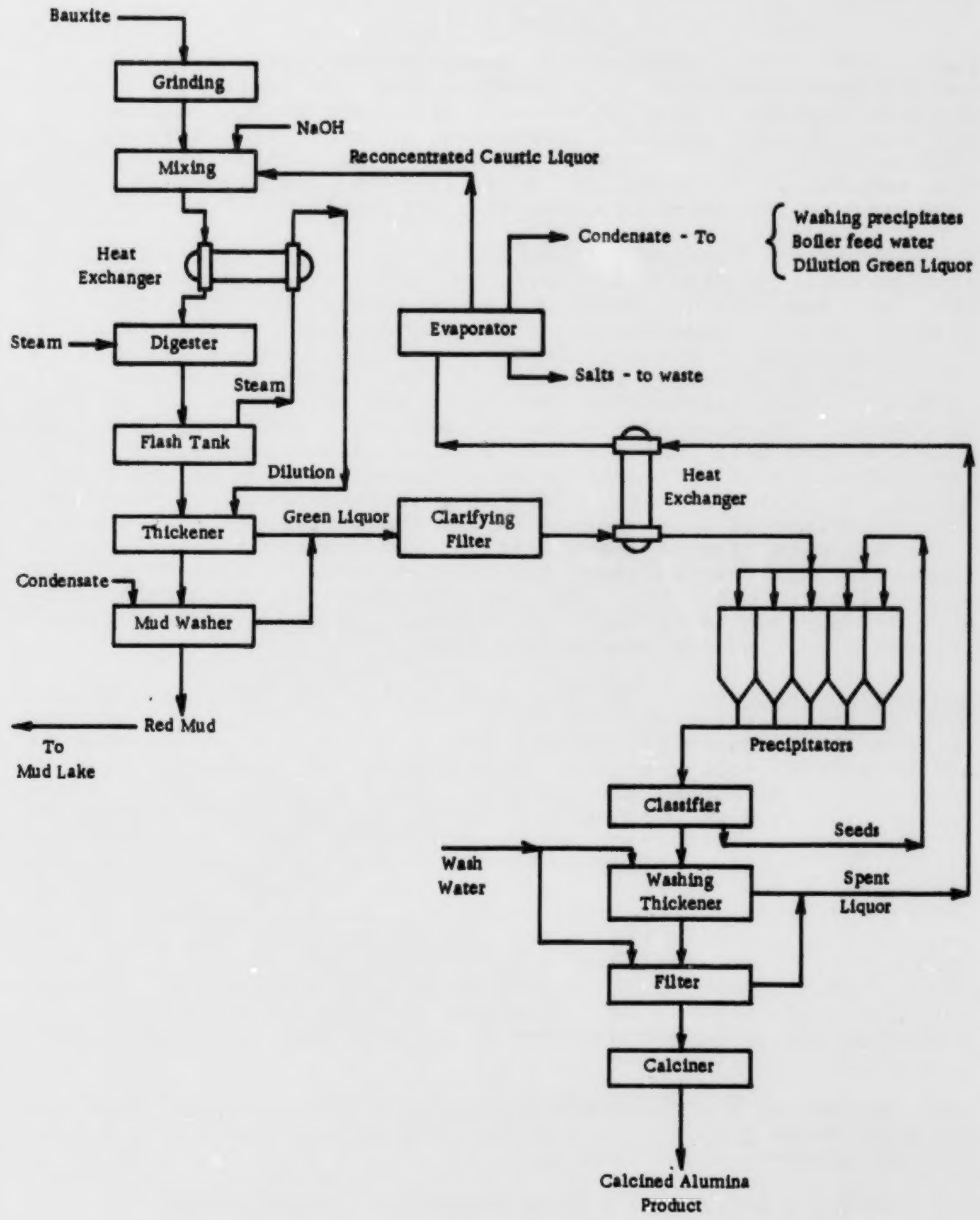

Bauxite
Grinding
NaOH
Mixing
Reconcentrated Caustic Liquor
Heat Exchanger
Condensate - To
Washing precipitates
Boiler feed water
Dilution Green Liquor
Evaporator
Steam
Digester
Steam
Salts - to waste
Flash Tank
Dilution
Heat Exchanger
Thickener
Green Liquor
Clarifying Filter
Condensate
Mud Washer
Red Mud
To Mud Lake
Precipitators
Classifier
Seeds
Wash Water
Washing Thickener
Spent Liquor
Filter
Calciner
Calcined Alumina Product

Figure 2. Generalized diagram of the Bayer Process.

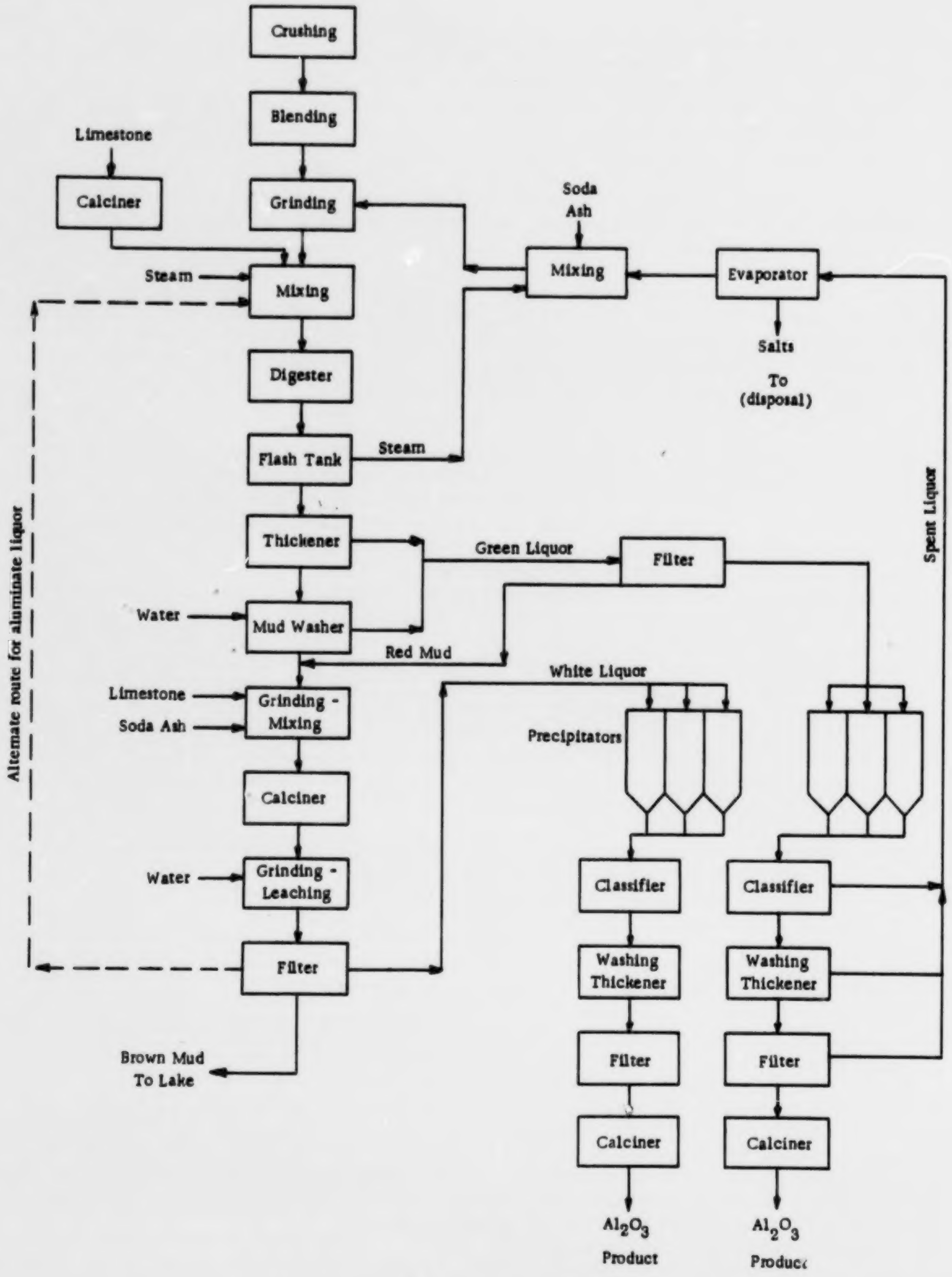

Crushing
Blending
Limestone
Calciner
Grinding
Soda
Ash
Mixing
Evaporator
Steam
Mixing
Salts
To
(disposal)
Digester
Flash Tank
Steam
Spent Liquor
Alternate route for aluminate liquor
Thickener
Green Liquor
Filter
Water
Mud Washer
Red Mud
White Liquor
Limestone
Soda Ash
Grinding - Mixing
Precipitators
Calciner
Water
Grinding - Leaching
Classifier
Classifier
Filter
Washing Thickener
Washing Thickener
Brown Mud
To Lake
Filter
Filter
Calciner
Calciner
Al_2O_3
Product
Al_2O_3
Product

Figure 3. Generalized diagram of the Combination Process.

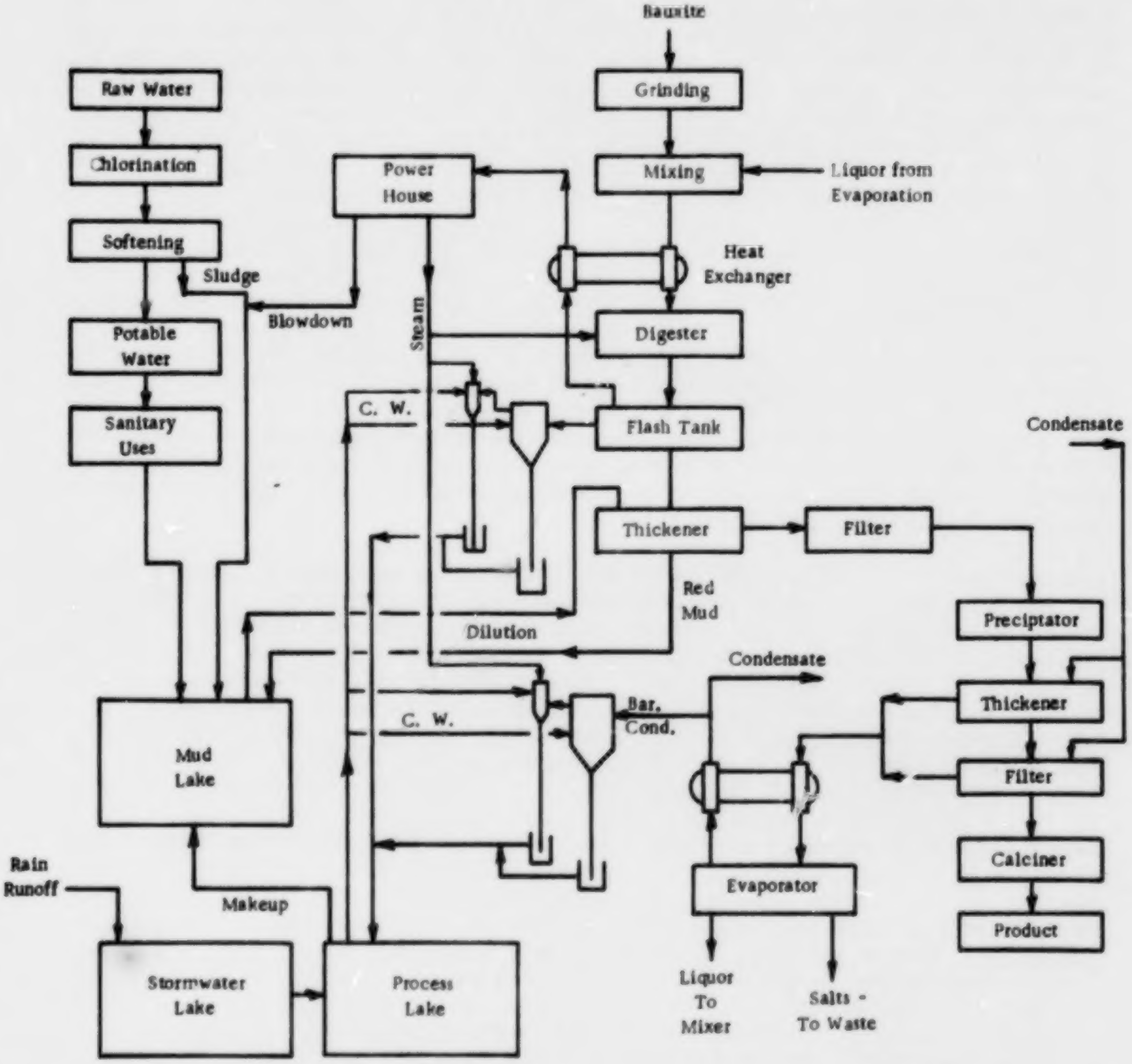
and washing. Precipitation may take one to three days. The precipitated trihydrate (aluminum hydroxide) is dewatered and fed to calcination which transforms the alumina to the anhydrous crystalline form, most suitable for later use in the electrolytic reduction to aluminum metal. Much of the alumina produced by the combination process from Arkansas bauxite is utilized for other purposes than the production of aluminum metal. These include refractories, electrical insulators, catalyst supports, ceramics, abrasives and polishes, heat exchange media, activated alumina, and chemical alums.

A large percentage of U.S. production of gallium, used in transitors, results as a by-product of the refining of Arkansas bauxite. The gallium occurs in the ore as a trace element and is recovered from the process for its commercial value. This recovery operation is associated only with one plant operating on a specific ore.

Water Circuit. The general pattern of water usage includes the use of water for leaching solutions, washing of precipitates, considerable use for heat exchange purposes in connection with the control of temperatures in the reaction (i.e., steam heating, flash evaporation or multiple-effect evaporators, etc.), and other steps of the chemical extraction process. From the viewpoint of water recirculation or discharge, the major feature of all water circuits is the red or brown mud lake operated at nearly all alumina refineries. This lake is analagous to a tailings pond in a flotation concentrator operation. The mud lake serves as a receiver of solid residues, a receiver and reservoir of process water, a point of loss by evaporation and seepage, and a collector of rainfall. Since some minimum amount of water is required by the mechanics of flushing the material to the disposal site, water also serves as the transport medium of the waste portion of the ore to the lake.

In general, the standard or combination Bayer process has no large demand for water for air pollution control. The processes used are essentially carried out in closed vessels. As with any plant, a sanitary water circuit is part of the operation, requiring a source of potable water. Disposal may be to a municipal sewer system, a plant sewer system, or to the red mud lake, with or without any form of treatment.

Although all plants use either the Bayer or the combination process, no two plants are alike with respect to water treatment and management schemes. This makes characterizing plant effluents somewhat complicated. Location, climate, type of ore, and waste management philosphy all contribute to different approaches to waste water management. Seven of the nine U.S. bauxite refineries already practice total impoundment of mud wastes. A very generalized water flow diagram for a bauxite refinery practicing total impoundment is shown in Figure 4. While the diagram shows intake water treatment, sanitary uses, and boiler plant water streams, these streams are not considered


Bauxite
Raw Water
Grinding
Chlorination
Power House
Mixing
Liquor from Evaporation
Softening
Heat Exchanger
Sludge
Blowdown
Steam
Potable Water
Digester
Sanitary Uses
C. W.
Flash Tank
Condensate
Thickener
Filter
Red Mud
Preciptator
Dilution
Condensate
Thickener
Bar. Cond.
C. W.
Mud Lake
Filter
Calciner
Rain Runoff
Evaporator
Makeup
Product
Stormwater Lake
Process Lake
Liquor To Mixer
Salts - To Waste

C. W. - Cooling Water

Figure 4. Generalized diagram of water circuit for Bayer plant employing total impoundment.

to be bauxite process streams, and are shown merely to complete the water circuit.

Since most of the industry uses total recycle of the main process stream and normally concerns itself with only combined streams, complete analyses for process waste streams are not readily available. The principal waste stream is the red mud stream. When this is routed to a red mud lake, as part of a closed water circuit, the parameter of concern is the alkalinity of the recycling lake water. This is kept low because the lake serves as an additional washing stage. Other ions in this recycle stream (e.g., sulfate) are monitored only to the extent that their levels will not interfere with plant operation.

A refinery may have, in addition to the main red mud lake, a process water lake and a storm water lake. In addition, the minor remaining storage capacity in abandoned red mud lakes may be utilized to dispose of small quantities of aqueous wastes intolerable in the recycle circuit. An example of this is the sulfate streams resulting from acid cleaning of equipment or from salting-out evaporators. A process water lake can be thought of as a recycle reservoir used for higher grade operations than the red mud lake, which has a lower alkalinity and generally a higher water quality. It may also be used as a source of makeup water for the mud lake circuit.

A storm water lake may be used to collect storm water runoff from the plant site. Since the surface areas encompassed by a bauxite refinery complex will range from a minimum of several hundred acres to a thousand acres or more, very large volumes of storm water must be planned for. This problem is discussed in some detail later. Normally, a bauxite refinery will maintain its main process water stream in approximate balance. In most cases, there will be a large circulating load, tens of thousands of liters per minute, but makeup additions will be relatively minor.

The prinicipal water streams in a bauxite refinery are the following:

Red mud stream
Spent liquor
Condensates
Barometric condenser cooling water
Miscellaneous cooling water streams
Miscellaneous waste streams
Storm water runoff.

Red Mud Stream. Red mud is the insoluble residue remaining after extraction of the alumina from bauxite. In the case of the combination process used for Arkansas ore the final residue is brown mud, but the same considerations apply. After filtration or thickening to separate the pregnant sodium aluminate liquor from the red mud gangue, the mud is pumped to disposal. If not already at a pumpable consistency, it is first diluted. Disposal may be to a river (two plants) or to a red mud lake (seven plants). If disposed of to a river, the mud is further diluted to 0.5-1.5 percent solids to insure that rapid settling does not occur at the point of discharge. Depending upon the bauxite ore, the residue may range between 0.33 ton/ton of Al_2O_3 produced (Surinam bauxite) to 2 tons/ton (Arkansas bauxite). At 17-20 percent solids, the water going to the red mud lake will approximate 1,900,000 to 18,000,000 liters/day (500,000 to 4,800,000 gal/day). Not all of this water returns to the plant since the terminal density of the settled solids may range from 35 to 75 percent. A substantial amount of water is retained in the mud. This is one manner in which water is rejected from the process water circuit.

Spent Liquor. After separation from the mud residue, either by filtration or by countercurrent decantation plus a polishing filtration, the pregnant liquor is cooled, diluted and sent to the precipitators. Here, fine seeds of hydrated alumina are added and after a cooling period of 1-3 days, the solution hydrolyzes and the alumina precipitates as alumina hydroxide.

After filtration of the product alumina trihydrate, the spent liquor is heated and concentrated for return to the digester. Thus, the spent liquor is not a waste stream, although some wastes may be withdrawn from it. In order to control buildup of contaminants which might either retard precipitation or precipitate with the product in the process liquor, a portion of the spent liquor may be passed through a salting-out evaporator, where it is evaporated to low volume in order to eliminate contaminants, particularly sulfates. To prevent redissolution of sulfates and their return to the process, the sulfate slurry is normally disposed of to an abandoned mud lake or to a land fill. The discharge of such wastes to surface waters was not observed in any plant.

In another scavenging scheme, soluble contaminants tending to build up in the spent liquor are allowed to adsorb and/or precipitate on the bauxite slurry from the digesters. This is accomplished by mixing spent liquor with the bauxite slurry, cooling and diluting it before filtration, and allowing sufficient contact time for the scavenging to occur. After this, the red mud is filtered off and rejected. This scheme performs satisfactorily for one producer, and eliminates a need for a salting-out evaporator.

Condensates. Numerous large scale evaporation operations are carried out in bauxite refineries. The high temperature, high pressure slurry from the digesters is flashed down to atmospheric pressure for filtration or thickening. The still-hot clarified pregnant liquor may be vacuum-flashed to cool it for precipitation. The spent liquor after precipitation is evaporated to concentrate it. All of these operations produce steam which is generally condensed in a heat exchanger to heat a process stream. These steam condensates are high quality waters, and are normally utilized for the most demanding plant uses (i.e., boiler-feed water, product washing, and final washing of red muds). However, in some plants where the water balance is in excess, some condensates may be rejected as a waste discharge.

Barometric Condenser Cooling Water. As noted in the preceding section, cooling and concentration in evaporators is a common feature of most bauxite refineries. However, one refinery, processing high-grade Surinam bauxite by careful management of the process water circuit, is able to avoid the use of evaporators and barometric condensers. In most cases, in the last stage, the multi-effect evaporators are under a relatively high vacuum. Surface condensers are much more expensive than barometric condensers and use more water. They are not used as evaporators unless the vapor to be condensed must be recovered separately from the cooling water. Thus, barometric condensers are invariably used in the bauxite refining industry. Barometric condensers are large consumers of water, and the water management scheme adopted will depend upon water availability, water balance considerations, and effluent discharge requirements.

Where a negative system water balance exists and water conservation measures are practiced, the barometric condenser water loop will be closed, using the red mud lake or other process water. Where the process water system tends toward a positive balance, or where ample supplies of water of satisfactory quality are available, a once- through scheme may be adopted, with the effluent rejected to a nearby surface water.

Water quantities required by barometric condensers used in this service are large, characteristically several thousand liters/minute for each condenser. Water used may be as much as 20,000-40,000 liters/ton (5,000-10,000 gallons/ton) of product. Theoretically, the overhead vapors to be condensed should approach distilled water in composition. When entrainment occurs, alkali and aluminum values will be carried over and will appear in the effluent from the barometric condenser hot-well. If this is discharged to a receiving water containing dissolved magnesium or calcium compounds, these will be precipitated as visible white hydroxides. Normally, entrainment will be minimal from a well designed and operated evaporator and will reach unsatisfactory levels only during periods of upset. Incorporation of suitable demisters in the evaporator vapor space will further minimize entrainment.

Miscellaneous Cooling Water Streams. Normally, the various cooling streams in a bauxite refinery come from air compressor aftercoolers and various cooling duties associated with the rotary calcining kilns. These are characteristically non-contact services.

Storm Water Runoff. Storm water runoff from bauxite refinery sites may comprise a significant volume. This results from the large ground areas occupied and general location in regions with high and occasionally torrential rainfalls. There are no known data on the changes in alkalinity of runoff water as a function of amount of rainfall for a single storm, but it would be anticipated that the first portion of a rain would remove any superficial alkaline dust, and that alkalinity of the runoff would decrease thereafter.

If the plant areas were smaller or refineries were located in more arid areas, storm water runoff would be of little consequence. However, all bauxite refineries in the continental United States have histories showing storm-type rainfalls. Illustrative of the maximum rates of rainfalls which can be experienced in these regions are some historical data from U.S. Weather Bureau Records (Table 3). For example, during this study about 60 cm (24 in) of rainfall were accumulated over a three-day period in one area of the Texas Gulf Coast (3).

Current technology for control of storm water runoff appears to be the selection of a maximum rainfall rate which can be collected, and to divert storm water runoff, accumulating at greater rates than this, by overflow weirs or similar arrangements. One plant, for example, can collect and store rainfall up to a rate of 7.6 cm (3 inch) per hour; rainfall at rates greater than this is diverted to a nearby waterway. Storm water runoff from rains exceeding this rate are considered by the plant to be either essentially uncontaminated by process pollutants, or so extremely dilute that any contaminants are below significant levels.

Mass Water Balance in a Bauxite Refinery. A better understanding of the state-of-the-art of treatment technology and the factors affecting the feasibility of total impoundment is gained when the possible water gains and losses in a bauxite refinery are considered. Although these will vary, the following summarizes the main sources of gain and loss:

Water Gains. In most cases, refineries processing imported ores will not gain water from them, since these ores are dried before shipment and normally stored under cover before use. If outdoor storage piles are used, some moisture will enter with the ore. Domestic ore (Arkansas) is not dried before processing, and there is a definite water gain from this source. Almost all plants have a fresh water intake, although this quantity is highly variable. Water intake may be needed for potable purposes, boiler feed water, barometric condensers, washing precipitated aluminum hydroxide, or makeup for water losses from the circuit.

The other large and uncontrollable cause of water gain is rainfall. Since bauxite refineries occupy large areas, runoff quantities can significantly affect the water balance. There is some possibility of diverting rainfall on plant grounds so that it does not enter the water circuit. However, rain which falls on mud lakes enters the water circuit directly, and can represent a sizable water gain. For example, 31 cm (1 ft) of rain on a 40.5 ha (100 ac) mud lake is equal to a little over 125,000,000 liters (33,000,000 gal), and can accumulate in as little as 24 hours (Table 3).

TABLE 3. MAXIMUM RAINFALLS(a)

<table>
<tr><th rowspan="2">Location</th><th colspan="6">Cumulative Rainfall, cm (in.)</th></tr>
<tr><th>1-hr</th><th>2-hr</th><th>3-hr</th><th>6-hr</th><th>12-hr</th><th>24-hr</th></tr>
<tr><td>Little Rock, Arkansas</td><td>7.62 (3.00)</td><td>11.68 (4.60)</td><td>17.32 (6.82)</td><td>19.50 (7.68)</td><td>20.80 (8.19)</td><td>24.33 (9.58)</td></tr>
<tr><td>Year</td><td colspan="4">← 1955 →</td><td>1913</td><td>1913</td></tr>
<tr><td>Mobile, Alabama</td><td>8.91 (3.51)</td><td>11.35 (4.47)</td><td>12.70 (5.00)</td><td>20.88 (8.22)</td><td>32.97 (12.98)</td><td>33.93 (13.36)</td></tr>
<tr><td>Year</td><td>1947</td><td>1922</td><td>1900</td><td>1911</td><td>1900</td><td>1955</td></tr>
<tr><td>Baton Rouge, Louisiana</td><td>6.12 (2.41)</td><td>9.27 (3.65)</td><td>11.56 (4.55)</td><td>12.34 (4.86)</td><td>12.60 (4.96)</td><td>21.34 (8.40)</td></tr>
<tr><td>Year</td><td>1959</td><td colspan="4">← 1954 →</td><td>1947</td></tr>
<tr><td>New Orleans, Louisiana</td><td>11.97 (4.71)</td><td>14.91 (5.87)</td><td>16.61 (6.54)</td><td>21.89 (8.62)</td><td>32.41 (12.76)</td><td>35.58 (14.01)</td></tr>
<tr><td>Year</td><td colspan="2">← 1953 →</td><td>1927</td><td>1929</td><td colspan="2">← 1927 →</td></tr>
<tr><td>Corpus Christi, Texas</td><td>9.22 (3.63)</td><td>11.81 (4.65)</td><td>13.59 (5.35)</td><td>15.95 (6.28)</td><td>17.78 (7.00)</td><td>20.98 (8.26)</td></tr>
<tr><td>Year</td><td>1928</td><td>1960</td><td>1956</td><td colspan="2">— 1931 →</td><td>1924</td></tr>
<tr><td>Victoria, Texas</td><td>7.87 (3.10)</td><td>11.81 (4.65)</td><td>15.62 (6.15)</td><td>18.67 (7.35)</td><td>20.19 (7.95)</td><td>22.02 (8.67)</td></tr>
<tr><td>Year</td><td colspan="6">← 1960 →</td></tr>
</table>

(a) Data through 1961.

Reference: The Water Encyclopedia.(4)

Water Losses. Water losses in a bauxite refinery may arise from the following:

Drying and calcining of product.
Red mud.
Evaporative cooling of green liquor.
Concentration of spent liquor.
Evaporation from lakes.
Seepage.
Red mud calcination (combination process).

Drying and calcining of product: The precipitated aluminum hydroxide, $Al(OH)_3$, is filtered from the spent liquor, washed to displace the entrapped caustic solution, dried, and calcined. Assuming a 50 percent solids cake from the filter, a ton of water is evaporated for each ton of alumina product (i.e., 520 to 3600 kkg (575 to 4000 ton) water).

Red mud: The red or brown mud carries water, which is not reclaimed. Even when fully consolidated, the mud in a lake may contain more than 50 percent moisture. This is approximately one ton of water loss for each ton of mud. This loss will vary on an alumina basis due to the range for various bauxite ores of from 0.33 to 2.0 tons mud per ton Al_2O_3 produced.

Evaporative cooling of green liquor: Evaporation is a ubiquitous operation in a bauxite refinery. It occurs first in cooling the bauxite slurry issuing from the digesters. Typically, the green liquor slurry from the digesters will be blown down (flashed) to atmospheric pressure in several stages. The vapors released will be condensed and reused as boiler feed water, cake washing, or dilution of the filtered pregnant liquor before precipitation. It is not normally discarded. The general system was described by Hudson, (5) and is illustrated by the flowsheet in Figure 5. Although the slurry must be cooled before going to the precipitators, recovery of heat is an equally important objective. The steam from the flash tanks is used in the shell side of tubular heat exchangers to heat the process liquor recycling to the digesters. As indicated by Figure 5, a portion of the liquor is diverted through the mixer where the liquor and bauxite are combined.

The final stage of cooling the green liquor before filtration or countercurrent decantation of the mud may be performed by an evaporator operating under vacuum. The vapors released are condensed in a barometric condenser. There are several possibilities for disposal of the mixture of cooling water and process condensate from the barometric condenser. It may be contained in a totally closed circuit, with the effluent going to the lake or cooling tower from which the condenser cooling water is drawn. The barometric condenser may use once-through cooling water, in which case the mixed effluent is discharged from the plant to a waterway and represents a water loss.

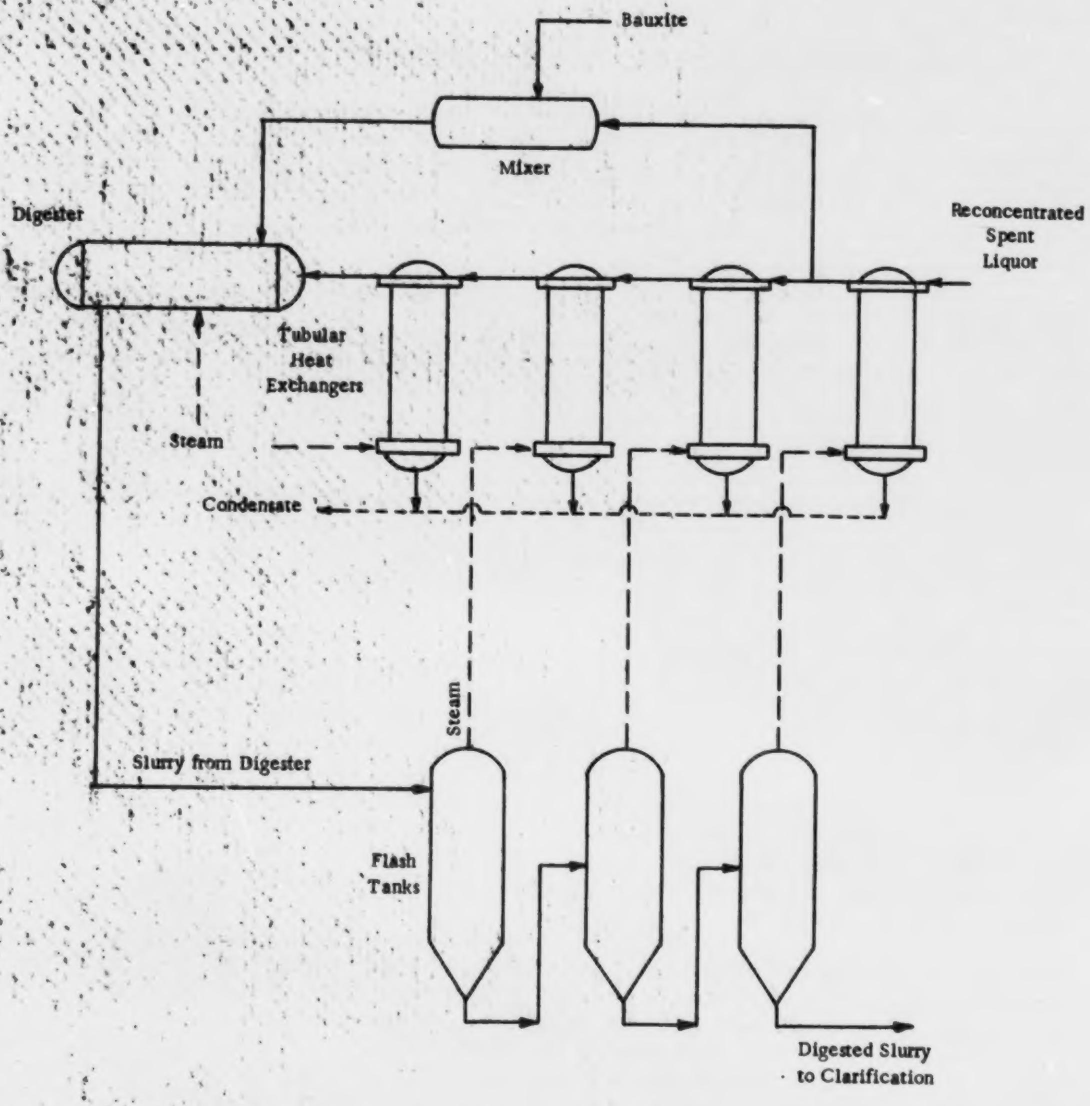

Bauxite
Mixer
Digester
Reconcentrated Spent Liquor
Tubular Heat Exchangers
Steam
Condensate
Steam
Slurry from Digester
Flash Tanks
Digested Slurry to Clarification

Figure 5. Flowsheet of digestion and heat recovery system.

The pregnant liquor filtrate from the red mud separation step also needs further cooling before going to the precipitators. This cooling may be done through evaporation or in heat exchangers against the cold spent liquor enroute to the evaporators. The effluent from the barometric condenser generally will go to a reservoir for recycle to the process.

Concentration of spent liquor: A large heat duty is associated with the concentration for reuse of the spent liquor filtrates from separation of the aluminum hydroxide product from the mother liquor. Typically, the multistage evaporators used will concentrate the liquor from about 150 g/l to about 170 g/l Na_2O_3 (113 g/l to 128 g/l NaOH). Again, the vapor from the first stages will generally be condensed against some cold process stream, but the last stage will be under high vacuum and will utilize a barometric condenser. Depending on the balance in the water circuit and the availability of the large quantities of water needed for a barometric condenser, the effluent will be discharged to a waterway or recycled to an impoundment lake in the plant water circuit. If efficiently operated, there will not be any appreciable carryover of caustic from an evaporator to a barometric condenser.

Evaporation from lakes: The area of a bauxite refinery's red mud lake may vary from 40 to 800 ha (100 to 2000 ac). In addition, a plant may have a series of lakes (process lakes, clear water lakes, storm water lakes, etc.) used for other purposes. Depending on the geographical location of a refinery, these lakes may serve as net evaporators or net collectors. In more arid locations along the Texas Gulf Coast, these lakes may be a source of water loss; further east, in southern Louisiana or Alabama, the reverse may be true. Table 4 depicts this situation, showing average rainfall and mean annual lake evaporation, the latter data taken from Figure 6.

Seepage: Seepage from lakes is a possible minor source of water loss. However, in constructing a lake, attempts are made to insure that the bottom provides an impervious layer. A ditch surrounds the red mud lake dikes, in which any minor seepage will be collected and pumped back to the lake. General practice is to monitor this ditch by survey wells located around the lake. Ground water does not exit the property through a recognizable or identifiable outfall. Based on information supplied by plant operators, there is no evidence to suggest that this is a pollution problem to either surface or ground waters.

Red mud calcination: One special case of water loss is in the red mud calcination peculiar to combination process bauxite refineries. The red mud from the first stage is retreatd by mixing with soda ash and lime and than calcined. The red mud underflow from the countercurrent decantation unit, at 25 percent solids, generally will undergo pressure filtration, possibly to 40-50 percent solids, to reduce the water content and the evaporative load. This will represent a loss from the system of about a ton of water per ton of red mud processed.

TABLE 4. RAINFALL AND EVAPORATION DATA

Location	Rainfall Data[a] cm	Rainfall Data[a] (in.)	Rainfall Data[a] Years	Mean Annual Lake Evaporation[b] cm	Mean Annual Lake Evaporation[b] (in.)	Average Net Accumulation cm	Average Net Accumulation (in.)
Little Rock, Ark./Robinson AAF	128	(50.3)	9	109	(~43)	18	(~7)
Little Rock, Ark./Adams Field	126	(49.5)	23				
Mobile, Ala./Bates Field	158	(62.2)	90	119	(~47)	37	(~14)
Mobile, Ala./Brookley AFB	154	(60.7)	12				
Baton Rouge, La./Downtown	133	(52.3)	16	124	(~49)	9	(~3)
New Orleans, La./Moissant Field	146	(57.4)	84	124	(~49)	22	(~9)
Corpus Christi, Tex./Cuddihy Field	72	(28.3)	19	140	(~55)	68	(~27)
Matagorda Island, Tex.	94	(37.1)	12	140	(~55)	46	(~18)

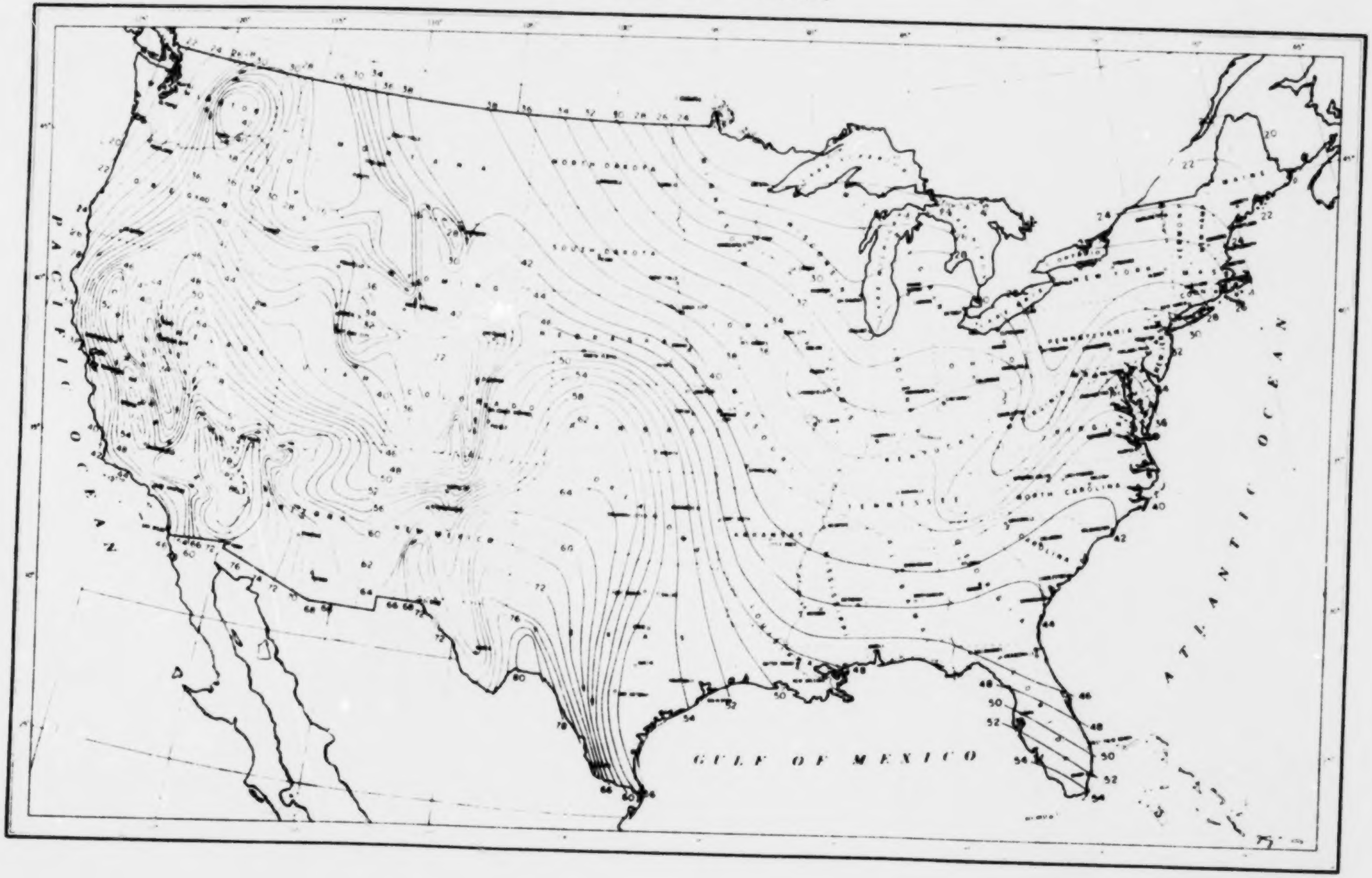
(a) U.S. Naval Weather Service World-Wide Airfield Summaries.(5)

(b) The Water Encyclopedia(4) (see Figure 6).

Figure 6. Mean annual evaporation in the United States.

(Source: U.S. Weather Bureau)

[Values in inches for period 1946-55.]


PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEW MEXICO
TENNESSEE
NORTH CAROLINA

Summary. As described in the foregoing paragraphs, there is fundamentally only one process for refining bauxite, the Bayer process. The combination process, a variation of the Bayer process, retreats the red mud waste from the Bayer process to recover additional aluminum and alkali values. Upon review of both methods, it is concluded that the differences in manufacturing processes do not warrant further subcategorization.

Various means of condensation create varying quantities of waste water. When barometric condensers are utilized, large quantities of cooling water are required which may create an imbalance in the water circuit. While these differences may justify adoption of a different configuration or management of some water circuits, there is no justification for establishment of a subcategory to provide for them.

Raw Materials

The raw material for all U.S. alumina refineries is bauxite, an ore of aluminum which consists of hydrated alumina ($Al_2O_3 \cdot 3H_2O$), known as gibbsite or hydrargillite.

This classification is of great practical importance in processing, as the methods used to treat bauxites in order to extract pure alumina are based on attacking the bauxites with caustic soda. The trihydrate is much more soluble in alkali than are the monohydrates, and processing conditions are appreciably milder. Most of the bauxite processed in the United States is predominantly of the trihydrate variety.

The suitablity of a bauxite as a raw material for aluminum extraction depends on its alumina content and on its content of combined silica in the form of kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Not only does such a silicate, if present, tie up a certain amount of alumina that cannot be extracted, but, in the course of treatment entails a heavy and expensive loss of caustic soda in the form of insoluble sodium aluminum silicate compounds (such as sodalite, $3Na_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2NaCl$, and cancrinite, $(Na,K)(Al,Si)_2O_4$). Each kilogram of SiO_2 in the bauxite involves the loss of approximately 1 kilogram of Al_2O_3 and 0.6 to 0.7 kilogram of Na_2O.

The composition of the bauxite used in alumina production varies a great deal. The variations generally fall within the following limits shown in Table 5.

TABLE 5. RANGE OF COMPOSITION OF BAUXITES FOR ALUMINA PRODUCTION

Composition	Weight Percent
Al_2O_3, total	40 to 60
SiO_2, free and combined	1 to 20
Fe_2O_3	7 to 30
TiO_2	3 to 4
P_2O_5, V_2O_5, etc.	0.05 to 0.20
H_2O, combined	12 to 30

Reference: Kirk-Othmer (7).

There are other ores of aluminum, such as nepheline, a double silicate of alumina and an alkali metal, and alunite, a hydrous potassium aluminum sulfate, $K(AlO)_3(SO_4)_2\cdot 3H_2O$. The treatment of these ores is complicated and expensive, and no other ores except bauxite are commercially processed in the United States.

Most of the bauxite used in the United States is imported. Jamaica and Surinam (formerly Dutch Guiana) are the principal suppliers. Some comes from Australia, Guinea (formerly French Guiana), Haiti, and South America. The only commercial deposits in the United States are in Arkansas, and are used by two bauxite refineries located nearby. The differences in ore composition mentioned previously are illustrated by typical analyses supplied by the producers for these ores (as shown in Table 6).

The silica content in imported ores is not high enough to warrant other than the basic Bayer process. It is less expensive to accept the losses of alumina and caustic discussed above than to attempt to recover them. However, the average silica content of Arkansas ores is now in the 13 to 20 percent range. Ores as low as 6 percent SiO_2 occurred in the past in the area, but these were "high-graded" during World War II. There is considerable variation over this mineralized area, and selective mining is practiced to produce a uniform feed material.

In order to avoid the high losses of alumina and alkali, which would occur as a result of the high silica content, the "combination" process is employed for Arkansas ores. In this process the red mud residue from the Bayer process, containing alumina and soda values insolubilized as sodium aluminum silicate, is sintered with lime soda ash. The lime ties up the silica as calcium silicate, and the soda ash promotes the formation of sodium aluminate, which is then leached out and precipitated in the usual fashion. The resultant solid residue from the second leaching is known as "brown mud". Its calcium silicate content confers some of the properties of a hydraulic cement upon it, and brown mud can be safely accumulated in mud lakes to considerable heights.

In summary, the bauxite ores processed in the United States are essentially all trihydrate-type ores, more amenable to control and treatment than the monohydrate ores common to European deposits. Even in the ores least amenable to treatment, 80 percent of the alumina is of the trihydrate form. The best ores contain 95 percent of the alumina in trihydrate form. In any case, the chief effect of the higher monohydrate content is to require a higher temperature and pressure in the digesters. The quantity and quality of wastes generated is not significantly affected. Accordingly, a subcategory based upon raw material differences is not warranted.

If imported bauxite ceases to become freely available at a competitive price, other domestic ores such as nepheline or anorthosite, $CaO\cdot Al_2O_3\cdot 2SiO_2$, may be used. No domestic plants

TABLE 6. CHARACTERISTIC ANALYSES FOR VARIOUS BAUXITES

	Weight Percent			
	Jamaican	Surinam	Arkansas	Guiana
Al_2O_3, total	49.0	59.8	48.7	58.6
SiO_2	0.8	3.8	15.3	4.9
Fe_2O_3	18.4	2.7	6.5	4.1
TiO_2	2.4	2.4	2.1	2.5
F	--	--	0.2	0.02
P_2O_5	0.7	0.06	--	--
V_2O_5	--	0.04	--	--
H_2O, combined	27.5	31.2	25.8	29.6
Al_2O_3, trihydrate	40-47	59.6	34.1	52.7
Al_2O_3, monohydrate	2-9	0.2	14.6	5.9

currently are using or plan to use such raw materials, but one producer has begun exploratory investigations.

Products Produced

The only product from U.S. bauxite refineries is purified alumina. Normally, this is calcined for use in the production of aluminum metal. There are no significant differences in product between the various producers. Minor quantities of other aluminum compounds are produced, but the tonnages are insignificant. There is no justification for further subcategorization based on products.

Wastes Generated

The major process waste associated with the refining of bauxite is the mud residue. There are differences between the residues from the Bayer process (red mud) and the residues left after this mud is retreated by means of the combination process (brown mud). These differences do not appreciably alter the problem of disposal. There are also differences in the amount of mud generated per ton of alumina produced depending upon the source of the bauxite. Only 1/3 ton/ton of alumina results from processing Surinam bauxite; about 1 ton/ton from Jamaican bauxite; and 2 to 2-1/2 tons/ton for Arkansas bauxite. However, these differences change the size, not the nature of the problem of disposal.

The bauxite refining industry has reduced itself to one category for mud wastes. Seven of the existing nine U.S. refineries practice total impoundment of the mud slurry waste stream. Two refineries currently are discharging the mud residues into the Mississippi River. Under a consent degree, these plants must convert to the equivalent of impoundment by 1975. Thus, by 1975 total impoundment of mud wastes will be universal for the industry.

As indicated by the process description in the preceding section, the red mud wastes are accompanied by alkaline process water containing some unrecovered aluminum. Because of the similarity of process technology, the differences from plant to plant in composition of the aqueous phase are minor. With respect to treatability of red (brown) mud wastes, the differences are insufficient to warrant establishment of subcategories based on types of mud. Substantiation for this judgment is provided by the current, or soon to be successful, total impoundment of each of the various types of mud.

All bauxite refineries use sulfuric acid for removing scale from heat exchangers, as well as filtration and other types of equipment. The resultant spent acid is generally neutralized with the alkaline mud waste in an active or abandoned mud lake. Other wastes which may be generated by bauxite refineries include the following:

Boiler blowdown.
Cooling tower blowdown.
Water softener sludges.
Sanitary waste effluents.

None of these effluents is unique to bauxite refining. Since none of these are process streams, they are not the subject of effluent limitations.

Plant Size and Age

The aluminum industry and the bauxite refining industry are new, relative to the other primary metals industries. The oldest bauxite refinery dates back only to 1938 and two were constructed during World War II by the Defense Plant Corporation. Four more refineries were constructed in the 1950's. Since then, only one has been constructed and it began operation in 1967. The only old bauxite refinery was shut down in 1957 and dismantled.

Because all refineries use bauxite ore and employ either the Bayer or combination process, there is a great deal of similarity between plants. One primary aluminum producer designed and built its own three plants and the two erected during World War II. Many components are of identical design.

The smallest bauxite refinery has a production capacity of 900 kkg (1000 tons)/day of Al_2O_3. The largest has a capacity of 3265 kkg (3600 tons)/day. A fourfold difference in plant size does not significantly affect the quality or quantity of waste water produced or its amenability to treatment. Thus, further subcategorization on the basis of the age or size of refineries is not justified.

Plant Location

As illustrated by Figure 1, two bauxite refineries are located near the domestic bauxite deposits in Arkansas. The rest of those in the continental United States use imported bauxite and are located in the South. These locations are accessible to deep water shipping, either directly on the coast, or along the Mississippi River.

The relationship between annual rainfall and annual evaporation may be significant for some plants. In some locations, such as western Texas, annual rainfall averages about 72 cm (30 inches)/year, while the annual evaporation rate is about 140 cm (60 inches)/year, a net deficit of 68 cm (30 inches)/year. Thus, management of red mud lakes and water balances in the water circuit is simplified. In southern Louisiana and Alabama, average annual rainfall is approximately 130-160 cm (51-62 inches)/year, while evaporation averages only about 120-140 cm (47-55 in)/yr, a net gain of 10-20 cm (4-8 in)/yr of rainfall. This excess water complicates the management of the red mud lakes and may pose a disposal problem.

Rainfall is important because of the large land areas characteristic of a bauxite refinery complex. Apart from the rainfall collected directly in the red mud lake, which unavoidably enters the water circuit, runoff from the plant site must also be managed. Since the plant area may comprise several thousand acres, the quantities of water collected can be large.

However, the differences between rainfall and evaporation for various locations are susceptible to control by design and process management. Runoff from plant sites can be discharged to its normal water course, if the plant is designed to segregate process waste waters and runoff. By allowing the discharge of net rainfall for each monthly period from the overflow of the impoundment areas, a subcategorization based upon plant location is not necessary.

Air Pollution Control Equipment

The principal air pollution problem in a bauxite refinery is the dust from the calcination of the alumina product. Electrostatic precipitators have been used in the past, but have not always provided adequate control. New designs for precipitators are being developed. Baghouses are also used for final cleanup after electrostatic precipitators. No plants use or plan to use wet scrubbers on this operation. Where wet scrubbers are used on other dust producing operations (e.g., lime kilns or conveyor transfer points), the waste effluent normally is recycled to the process or is included with the main red mud flow. Compared to the very large volumes of red mud, these streams are insignificant. Air pollution control equipment in bauxite refineries appears unlikely to have any significant effect upon aqueous effluents, and no further subcategorization is warranted.

SECTION V

WASTE CHARACTERIZATION

Introduction

The dominant waste from a bauxite refinery is the gangue material from the ore, known as red or brown mud, which is produced on a very large scale (500 to nearly 4,000 kkgs per day). The most common solution to this red mud waste problem is total impoundment, but the tonnages to be disposed of can make the problem difficult. Compared to the other wastes characteristic of bauxite refining, the red mud waste stream poses only minor problems.

Characteristics of Types of Wastes

Red Mud Wastes

Depending upon the type of bauxite used, from 1/3 ton to approximately one ton of red mud will be produced per ton of alumina. In the case of brown mud from Arkansas bauxite, this increases to 2 to 2 1/2 ton/ton. The red mud is the major waste stream from a bauxite refinery. It will generally issue from the washing thickeners at approximately 17 to 20 percent solids, and be pumped to a disposal lake. Iron impurities impart the red color to the mud. If derived from Jamaican or Arkansas bauxite, the red mud may contain as much as 50 percent iron.

Table 7 shows a typical chemical analysis of the insoluble solids in Jamaican red mud. 98.5 percent of the material consists of the oxides of only eight elements plus water and carbon dioxide. The remaining 1.5 percent consists of the oxides of metallic elements, such as MgO,K_2O,Cr_2O_3,ZnO,ZrO_2,NiO_2,V_2C_5,SrO, and others.

TABLE 7. RED MUD INSOLUBLE SOLIDS (a)

	Percent
Losson Ingition (LOI)	11.0
SiO_2	5.5
Al_2O_3	12.0
Fe_2O_3	49.5
P_2O_5	2.0
CaO	8.0
Na_2O	3.5
TiO_2	5.0
MnO_2	1.0
Miscellaneous	1.5

(a) Specific gravity = 3.6
Reference: Rushing (8)

"Poor crystallization and agglomeration have made mineral identification of red mud very difficult. By using X-ray diffraction, petrographic microscopy and differential thermal analysis, some of the mineral compounds have been identified. Predominant compounds are iron oxides, hematite, Fe_2O_3, and hydrated iron oxides such as goethite, $FeO(OH)$, and limonite, $FeO(OH) \cdot nH_2O + Fe_2O_3 \cdot nH_2O$. Other iron compounds such as jacobsite, $MnO \cdot Fe_2O_3$, magnetite, Fe_3O_4, hercynit, $FeO \cdot Al_2O_3$, and ilmenite, $FeO \cdot$, TiO_2 have been tentatively identified. Aluminum is present with silica in tentatively identified compounds such as pyrophyllite, $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, sarcolite, $(Ca,Na_2)3Al_2(SiO_4)_3$, or zunyite, $[Al(OH, F,Cl)_2]_6 \cdot Al_2Si_3O_{12}$, and in manganspinel, $MnO \cdot Al_2O_3$, gahnite, $ZnO \cdot Al_2O_3$, and beohmite, $Al_2O_3 \cdot H_2O$. Other minerals identified were alpha quartz, SiO_2., calcite, $CaCO_3$, and rutile, TiO_2." (8) Thus, red mud has a complex chemical makeup, dependent upon its parent bauxite ore, aluminum extraction techniques, and impurity control.

The principal soluble constituents found in a typical Jamaican red mud liquor at 17 percent solids are shown in Table 8. The concentrations of metallic elements, including those listed in Table 7, are small. The hydroxides of these non-amphoteric elements are quite insoluble. Also, the alkaline leaching process is almost totally specific for aluminum and results in a highly pure alumina product.

One of the characteristics of Jamaican red mud is its fine size. It has been reported (8) that wet screening showed a particle size distribution as shown in Table 9.

Of the 95 percent below 325 mesh (44 micron), about 60 percent was between 5 and 44 microns, and some 35 percent was less than 5 microns in size.

TABLE 8. RED MUD SLURRY SOLUBLE SOLIDS

Al_2O_3	2.5 g/kg liq.
NaOH	3.7 g/kg
Na_2CO_3	1.6 g/kg
Na_2SO_4	0.4 g/kg
NaCl	0.7 g/kg
$Na_2C_2O_4$	0.1 g/kg
Specific gravity	1.008
pH	12.5
BOD	6 ppm
COD	148 ppm

Reference: Rushing(8).

TABLE 9. SCREEN ANALYSIS OF RED MUD

Screen Mesh		Percent Dry Solids
	+10	0.0
-10	+20	0.2
-20	+50	0.8
-50	+100	0.8
-100	+200	0.8
-200	+325	1.9
-325		95.5

Reference: Rushing(8).

> "The small particle size of the red mud is similar to a material of about 3 percent fine sand, 62% silt, and 35% clay, but since few true clay minerals are present, the red mud will present physical properties of salty fines. Red mud slurry is moderately thixotropic in that the apparent viscosity decreases or the fluidity increases as the cumulative shear rate increases and acts as a Bingham plastic in that a yield stress must be exceeded before flow commences.
>
> "Jamaican red mud will reach a maximum compaction of about 35% solids if allowed to settle and compact below a layer of water. If the mud slurry is allowed to dry in air, surface cracking will start at about 28% solids. Desiccation fissuring will continue on air drying with a volume shrinkage. The volume of one ton of red mud solids at 80% solids will be 1/4 the volume required for one ton of mud at 35% solids. The air-dried mud will reslurry at solids contents less than 60%; however, if the drying is continued to solids contents greater than 60%, the dessicated mud agglomerates will not reslurry although there may be some parting of the lumps at fissure or crack planes." (8)

Red mud wastes contain significant amounts of suspended solids and alkalinity. Depending upon the number of mud washing stages, the water associated with the mud may contain 3-10 g/l alkalinity (expressed as Na_2CO_3), and 1-3 g/l of sodium aluminate. (Convention in the U.S. alumina industry is to express total alkalinity, including both NaOH and Na_2CO_3 as Na_2CO_3).

The ideal solution to the red mud problem would be to develop a use for it. An obvious possible application utilizes its high iron content (Table 10). Fursman, et al (10) describe a process based on sintering the red mud with carbon and limestone and melting the sinter in an electric furnace to produce a low purity iron which could be further processed into steel. Although the basic process has been further developed (11) it has not yet found commercial application. It may have some economic value in countries which have bauxite refineries, but produce little or no steel.

Other investigators have examined its applicability to the manufacture of portland cement, bricks, and road construction. (10) (12). But no domestic markets have yet been developed which will economically justify processing the waste red mud. Total impoundment however, affords the opportunity for reclamation of the red mud when an economic recovery process and adequate markets are developed.

Cleaning Acid Wastes

The thermal efficiency of a bauxite refinery, an important economic item, depends significantly upon the efficiency of the many heat exchangers used to transfer heat from hot to cold process streams. Many of the streams contain substantial

TABLE 10. RANGE OF CHEMICAL ANALYSES OF RED MUDS

	Weight Percent		
Component	Alcoa Mobile, Ala. (Surinam)	Reynolds Bauxite, Ark. (Arkansas)	Reynolds Corpus Christi, Texas (Jamaica)
Fe_2O_3	30-40	55-60	50-54
Al_2O_3	16-20	12-15	11-13
SiO_2	11-14	4-5	2.5-6
TiO_2	10-11	4-5	trace
CaO	5-6	5-10	6.5-8.5
Na_2O	6-8	2	1.5-5.0
Loss on ignition	10.7-11.4	5-10	10-13

Reference: IITRI Project No. G6015(9).

quantities of dissolved solids, and scaling of exchanger surfaces is a recurring problem. Acid cleaning is universally employed, generally with sulfuric acid. Small quantities of inhibited hydrochloric acid or acetic acid are sometimes used. Scaling is also a problem with filtration equipment and filter cloths, and similar cleaning procedures are used. Normally, the resulting spent acid is primarily a solution high in sulfates, but with only low to moderate free acid concentrations. These sulfate solutions are disposed of by most plants to active or, preferably, to abandoned mud lakes where the neutralization is completed. In a few instances they are neutralized and discharged to waterways but this procedure is being replaced by impoundment. The quantities of sulfuric acid used are not large, averaging about 0.453 to 0.907 kkg (0.5 to 1.0 tons) of acid per day.

Barometric Condenser Effluents

Possible pollutants from the barometric condensers operation are heat and alkalinity. As described earlier, sizable barometric condensers are found at nearly all bauxite refineries, where they are used on the evaporative coolers and the spent liquor evaporators. Illustrative of the heat duty are the data from one plant with five spent liquor evaporators. Here the barometric condensers averaged 126 l/sec (2000 gal/min) and the temperature rise was approximately 14°C (25°F), for a total heat duty of about 31 million kg-cal/hr (125 million BTU/hr). Entrainment of significant amounts of alkali to the barometric condenser effluent should be negligible except during periods of upset or abnormal operation. However, barometric condenser effluents will tend to have a pH over 7.

Thermal Effluents

Air compressor aftercoolers may also contribute heat to process streams. Compressed air is generally used in sizable amounts for agitation in the numerous precipitators in a bauxite refinery. Air from compressors is frequently passed through water-cooled aftercoolers to remove the heat of compression and cool the air. This service is a non-contact cooling application and the only pollutant the cooling water can acquire is heat.

Similarly, there may be other non-contact cooling water applications, from which thermal discharges may result, such as seal rings on rotary calcining kilns. Heat discharges from these ancillary services are nominal.

Miscellaneous Wastes

Several bauxite refineries operate rotary lime kilns to produce the lime needed to compensate for the carbonate accumulated in the process liquor, or for use in the combination process. Some plants use wet scrubbers on these lime kilns, from which a potential waste stream results, but the resultant hydrated lime slurry is invariably fed back to the process in order to utilize the contained lime, and is never discharged.

One miscellaneous waste stream from a bauxite refinery difficult to characterize is the "housekeeping" or "hose-down" stream. This results from minor spills, leaks, and wastes resulting from clean-ups. In most plants the inplant drains are connected to the storm sewer, which may be discharged to the storm water lake or to the red mud lake.

In most plants, all process areas, where aqueous spills are possible, are floored with concrete; curb about 6 inches high surrounds the entire area. Any spill is thus contained for recovery and controlled disposal. Several other waste streams may also be associated with the operation of a bauxite refinery. Examples of these are:

Sludge from treatment and softening of the raw intake water.

Spent regenerant from ion exchange treatment of intake water.

Boiler blowdown.

Cooling tower blowdown.

Treated sanitary waste effluent.

None of these streams is unique to bauxite refining. However, it should be noted that all of them fit very well into the total impoundment philosophy of disposal of process wastes from a bauxite refinery and would represent one increment percent to the normal red mud load. Effluent limitations for these streams have not been established inasmuch as they are not considered process waste streams.

The characterization of process waste streams from the refining of bauxite is summarized in Table 11.

TABLE 11. CHARACTERIZATION OF PRINCIPAL WASTE STREAMS FROM U.S. BAUXITE REFINERIES

Waste	Quantity	Characterization
Red mud	500-3600 T/D (dry basis)	15-20 % solids
	1,000-7,200 T/D (wet, settled)	5-12 g/l soda
	3,000-20,000 T/D (slurry at 18% solids)	2-5 g/l aluminum pH - 12.5
Spent Cleaning Acid	Variable, 5-10 T/week intermittently discharged	Na_2SO_4, plus some free H_2SO_4 HCl or HAc may also be used pH - 0
Salts from salting - out evaporator	Variable-estimated up to several thousand kg/day	Na_2SO_4 - alkaline pH - 12.5
Barometric condenser, C.W.*	Millions of liters/hr	Temp. rise of up to 15°C(25°F) may contain traces entrained alkali
Boiler and cooling tower blowdown	Variable - thousands of liters/day	Dilute alkaline solutions pH - 12.5
Water softener sludge	one to few T/D	Lime and suspended solids from intake water
Sanitary waste	375 liters/D/capita	B.O.D. 70 g (0.15 lb)/day/capita

*C.W.= Cooling Water

SECTION VI

SELECTION OF POLLUTANT PARAMETERS

Introduction

The waste water parameters of pollutional significance for the bauxite refining industry include:

Alkalinity
pH
Total dissolved solids
Total suspended solids
Sulfate

Since the waste streams are essentially inorganic, biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) are generally insignificant. On the basis of the evidence reviewed there are hazardous or potentially toxic substances in the wastes discharged from bauxite refineries. The use of waste water recycle systems, along with complete waste retention, permits the elimination of the discharge of all process waste water pollutants to receiving waters.

Rationale For Selection of Pollutant Parameters

pH, Acidity, and Alkalinity

Acidity and alkalinity are reciprocal terms. Acidity is produced by substances that yield hydrogen ions upon hydrolysis and alkalinity is produced by substances that yield hydroxyl ions. The terms "total acidity" and "total alkalinity" are often used to express the buffering capacity of a solution. Acidity in natural waters is caused by carbon dioxide, mineral acids, weakly dissociated acids, and the salts of strong acids and weak bases. Alkalinity is caused by strong bases and the salts of strong alkalies and weak acids.

The term pH is a logarithmic expression of the concentration of hydrogen ions. At a pH of 7, the hydrogen and hydroxyl ion concentrations are essentially equal and the water is neutral. Lower pH values indicate acidity while higher values indicate alkalinity. The relationship between pH and acidity or alkalinity is not necessarily linear or direct.

Waters with a pH below 6.0 are corrosive to water works structures, distribution lines, and household plumbing fixtures and can thus add such constituents to drinking water as iron, copper, zinc, cadmium and lead. The hydrogen ion concentration can affect the "taste" of the water. At a low pH water tastes "sour". The bactericidal effect of chlorine is weakened as the pH increases, and it is advantageous to keep the pH close to 7. This is very significant for providing safe drinking water.

Extremes of pH or rapid pH changes can exert stress conditions or kill aquatic life outright. Dead fish, associated algal blooms, and foul stenches are aesthetic liabilities of any waterway. Even moderate changes from "acceptable" criteria limits of pH are deleterious to some species. The relative toxicity to aquatic life of many materials is increased by changes in the water pH. Metalocyanide complexes can increase a thousand-fold in toxicity with a drop of 1.5 pH units. The availability of many nutrient substances varies with the alkalinity and acidity. Ammonia is more lethal with a higher pH.

The lacrimal fluid of the human eye has a pH of approximately 7.0 and a deviation of 0.1 pH unit from the norm may result in eye irritation for the swimmer. Appreciable irritation will cause severe pain.

Since the Bayer refining process uses a strong caustic solution, the process waste from a bauxite refinery will be alkaline. As indicated above, the principal effluents are alkaline, with a pH over 10.

Dissolved Solids

In natural waters the dissolved solids consist mainly of carbonates, chlorides, sulfates, phosphates, and possibly nitrates of calcium, magnesium, sodium, and potassium, with traces of iron, manganese and other substances.

Many communities in the United States and in other countries use water supplies containing 2000 to 4000 mg/l of dissolved salts, when no better water is available. Such waters are not palatable, may not quench thirst, and may have a laxative action on new users. Waters containing more than 4000 mg/l of total salts are generally considered unfit for human use, although in hot climates such higher salt concentrations can be tolerated whereas they could not be in temperate climates. Waters containing 5000 mg/l or more are reported to be bitter and act as bladder and intestinal irritants. It is generally agreed that the salt concentration of good, palatable water should not exceed 500 mg/l.

Limiting concentrations of dissolved solids for fresh-water fish may range from 5,000 to 10,000 mg/l, according to species and prior acclimatization. Some fish are adapted to living in more saline waters, and a few species of fresh-water forms have been found in natural waters with a salt concentration of 15,000 to 20,000 mg/l. Fish can slowly become acclimatized to higher salinities, but fish in waters of low salinity cannot survive sudden exposure to high salinities, such as those resulting from discharges of oil-well brines. Dissolved solids may influence the toxicity of heavy metals and organic compounds to fish and other aquatic life, primarily because of the antagonistic effect of hardness on metals.

Waters with total dissolved solids over 500 mg/l have decreasing utility as irrigation water. At 5,000 mg/l water has little or no value for irrigation.

Dissolved solids in industrial waters can cause foaming in boilers and cause interference with cleanliness, color, or taste of many finished products. High contents of dissolved solids also tend to accelerate corrosion.

Specific conductance is a measure of the capacity of water to convey an electric current. This property is related to the total concentration of ionized substances in water and water temperature. This property is frequently used as a substitute method of quickly estimating the dissolved solids concentration.

Dissolved solids will be high in effluents from a bauxite refining process and will include the alkalies sodium hydroxide and sodium carbonate, plus sodium sulfate, sodium aluminate and other lesser constituents such as sodium chloride and sodium oxalate. The total dissolved solids content is an aggregation of the components listed above and serves as an overall monitor of the effluent quality.

Total Suspended Solids

Suspended solids include both organic and inorganic materials. The inorganic components include sand, silt, and clay. The organic fraction includes such materials as grease, oil, tar, animal and vegetable fats, various fibers, sawdust, hair, and various materials from sewers. These solids may settle out rapidly and bottom deposits are often a mixture of both organic and inorganic solids. They adversely affect fisheries by covering the bottom of the stream or lake with a blanket of material that destroys the fish-food bottom fauna or the spawning ground of fish. Deposits containing organic materials may deplete bottom oxygen supplies and produce hydrogen sulfide, carbon dioxide, methane, and other noxious gases.

In raw water sources for domestic use, state and regional agencies generally specify that suspended solids in streams shall not be present in sufficient concentration to be objectionable or to interfere with normal treatment processes. Suspended solids in water may interfere with many industrial processes, and cause foaming in boilers, or encrustations on equipment exposed to water, especially as the temperature rises. Suspended solids are undesirable in water for textile industries; paper and pulp; beverages; dairy products; laundries; dyeing; photography; cooling systems, and power plants. Suspended particles also serve as a transport mechanism for pesticides and other substances which are readily sorbed into or onto clay particles.

Solids may be suspended in water for a time, and then settle to the bed of the stream or lake. These settleable solids discharged with man's wastes may be inert, slowly biodegradable materials, or rapidly decomposable substances. While in suspension, they increase the turbidity of the water, reduce light penetration and impair the photosynthetic activity of aquatic plants.

Solids in suspension are aesthetically displeasing. When they settle to form sludge deposits on the stream or lake bed, they are often much more damaging to the life in water, and they retain the capacity to displease the senses. Solids, when transformed to sludge deposits, may do a variety of damaging things, including blanketing the stream or lake bed and thereby destroying the living spaces for those benthic organisms that would otherwise occupy the habitat. When of an organic and therefore decomposable nature, solids use a portion or all of the dissolved oxygen available in the area. Organic materials also serve as a seemingly inexhaustible food source for sludgeworms and associated organisms.

Turbidity is principally a measure of the light absorbing properties of suspended solids. It is frequently used as a substitute method of quickly estimating the total suspended solids when the concentration is relatively low.

With a closed cycle and total impoundment of wastes, total suspended solids should be low in any effluents discharged. High suspended solids content would indicate a process upset or a containment failure and is included as a significant parameter to monitor such occurrences.

Sulfate

Sulfate concentrations in discharge streams and pH measurements, would be indicative of the release of spent acid cleaning solutions. Sulfate is an undesirable addition to navigable waters.

Rationale for Rejection of Other Waste Water Constituents as Pollutant Parameters

As suggested by the earlier process description and by the preceding list of pollutant parameters, the process of refining bauxite involves earthy inorganic minerals. Because of this, several commonly encountered waste water constituents are relatively unimportant as pollutants. These are noted below.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is a measure of the oxygen consuming capabilities of organic matter. The BOD does not in itself cause direct harm to a water system, but it does exert an indirect effect by depressing the oxygen content of the water. Sewage and other organic effluents during their processes of decomposition exert a BOD, which can have a catastrophic effect on the ecosystem by depleting the oxygen supply. Conditions are reached frequently where all of the oxygen is used and the continuing decay process causes the production of noxious gases such as hydrogen sulfide and methane. Water with a high BOD indicates the presence of decomposing organic matter and subsequent high bacterial counts that degrade its quality and potential uses.

Dissolved oxygen (DO) is a water quality constituent that, in appropriate concentrations, is essential not only to keep organisms living but also to sustain species reproduction, vigor, and the development of populations. Organisms undergo stress at reduced DO concentrations that make them less competitive and able to sustain their species within the aquatic environment. For example, reduced DO concentrations have been shown to interfere with fish population through delayed hatching of eggs, reduced size and vigor of embryos, production of deformities in young, interference with food digestion, acceleration of blood clotting, decreased tolerance to certain toxicants, reduced food efficiency and growth rate, and reduced maximum sustained swimming speed. Fish food organisms are likewise affected adversely in conditions with suppressed DO. Since all aerobic aquatic organisms need a certain amount of oxygen, the consequences of total lack of dissolved oxygen due to a high BOD can kill all inhabitants of the affected area.

If a high BOD is present, the quality of the water is usually visually degraded by the presence of decomposing materials and algae blooms due to the uptake of degraded materials that form the foodstuffs of the algal populations.

Since the process waste streams are essentially inorganic rather than organic, there is no significant BOD_5.

Chemical Oxygen Demand (COD)

The chemical oxygen demand in the process waste streams from a bauxite refining process will be insignificant because of the inorganic nature of the waste.

Oil and Grease

Oil and grease exhibit an oxygen demand. Oil emulsions may adhere to the gills of fish or coat and destroy algae or other plankton. Deposition of oil in the bottom sediments can serve to exhibit normal benthic growths, thus interrupting the aquatic food chain. Soluble and emulsified material ingested by fish may taint the flavor of the fish flesh. Water soluble components may exert toxic action on fish. Floating oil may reduce the reaeration of the water surface and in conjunction with emulsified oil may interfere with photosynthesis. Water insoluble components damage the plumage and coats of water animals and fowls. Oil and grease in a water can result in the formation of objectionable surface slicks preventing the full aesthetic enjoyment of the water.

Oil spills can damage the surface of boats and can destroy the aesthetic characteristics of beaches and shorelines.

Oil and grease are not normally found in the process waste streams. The only source of oil or grease would be from lubrication of process machinery. The contribution from this source is insignificant.

Temperature

Temperature is one of the most important and influential water quality characteristics. Temperature determines those species that may be present; it activates the hatching of young, regulates their activity, and stimulates or suppresses their growth and development; it attracts, and may kill when the water becomes too hot or becomes chilled too suddenly. Colder water generally suppresses development. Warmer water generally accelerates activity and may be a primary cause of aquatic plant nuisances when other environmental factors are suitable.

Temperature is a prime regulator of natural processes within the water environment. It governs physiological functions in organisms and, acting directly or indirectly in combination with other water quality constituents, it affects aquatic life with each change. These effects include chemical reaction rates, enzymatic functions, molecular movements, and molecular exchanges between membranes within and between the physiological systems and the organs of an animal.

Chemical reaction rates vary with temperature and generally increase as the temperature is increased. The solubility of gases in water varies with temperature. Dissolved oxygen is decreased by the decay or decomposition of dissolved organic substances and the decay rate increases as the temperature of the water increases reaching a maximum at about 30¼C (86¼F). The temperature of stream water, even during summer, is below the optimum for pollution-associated bacteria. Increasing the water temperature increases the bacterial multiplication rate when the environment is favorable and the food supply is abundant.

Reproduction cycles may be changed significantly by increased temperature because this function takes place under restricted temperature ranges. Spawning may not occur at all because temperatures are too high. Thus, a fish population may exist in a heated area only by continued immigration. Disregarding the decreased reproductive potential, water temperatures need not reach lethal levels to decimate a species. Temperatures that favor competitors, predators, parasites, and disease can destroy a species at levels far below those that are lethal.

Fish food organisms are altered severely when temperatures approach or exceed 90¼F. Predominant algal species change, primary production is decreased, and bottom associated organisms may be depleted or altered drastically in numbers and distribution. Increased water temperatures may cause aquatic plant nuisances when other environmental factors are favorable.

Synergistic actions of pollutants are more severe at higher water temperatures. Given amounts of domestic sewage, refinery wastes, oils, tars, insecticides, detergents, and fertilizers more rapidly deplete oxygen in water at higher temperatures, and the respective toxicities are likewise increased.

When water temperatures increase, the predominant algal species may change from diatoms to green algae, and finally at high temperatures to blue-green algae, because of species temperature preferentials. Blue-green algae can cause serious odor problems. The number and distribution of benthic organisms decreases as water temperatures increase above 90¼F, which is close to the tolerance limit for the population. This could seriously affect certain fish that depend on benthic organisms as a food source.

The cost of fish being attracted to heated water in winter months may be considerable, due to fish mortalities that may result when the fish return to the cooler water.

Rising temperatures stimulate the decomposition of sludge, formation of sludge gas, multiplication of saprophytic bacteria and fungi (particularly in the presence of organic wastes), and the consumption of oxygen by putrefactive processes, thus affecting the esthetic value of a water course.

In general, marine water temperatures do not change as rapidly or range as widely as those of freshwaters. Marine and estuarine fishes, therefore, are less tolerant of temperature variation. Although this limited tolerance is greater in estuarine than in open water marine species, temperature changes are more important to those fishes in estuaries and bays than to those in open marine areas, because of the nursery and replenishment functions of the estuary that can be adversely affected by extreme temperature changes.

Thermal economy is important to a bauxite refining process, so that thermal pollution is normally not significant. When once-through cooling is employed, temperature increases in receiving waters in the vicinity of outfalls will be noted and may be significant near barometric condenser discharges. There is no treatment technology for heat, other than its dissipation into some sink, either water, the ground, or the atmosphere. For the purposes of this document, control consists of preventing its dissipation into navigable waters.

Color

Color in bauxite refining effluents will usually result from suspended gangue material and will have the characteristic reddish-brown color of red mud. The parameter selected, total suspended solids, is considered a better measure of the presence of pollutants than color.

Turbidity

Turbidity is indirectly measured and controlled by the limitation on suspended solids.

Trace Metals

Assuming total impoundment of red mud, the hydroxides of the trace metals associated with the aluminum in bauxite are quite insoluble and should not leach from a properly designed and operated impoundment area.

SECTION VII

CONTROL AND TREATMENT TECHNOLOGY

Introduction

The control and treatment technologies for the waste streams of a bauxite refinery must be viewed in light of the unique circumstances applicable to this specific industry subcategory. The key factor is that bauxite refineries are hydrometallurgical plants producing enormous tonnages of an aqueous waste suspension. As illustrated in Table 11, these range from 454 to 3,265 kkg (500 to 3,600 ton)/day on a dry basis. On a settled mud basis these qualities approximately double. In terms of the slurry issuing from the process at 15 to 20 percent solids, the tonnages can exceed 18,140 kkg (20,000 ton)/day. There is no practicable or currently available treatment or control technology for such a waste except impoundment. Thus, as a basic operating premise, a bauxite refinery must provide a large diked area for impounding the red mud produced. This has been the case for all but two plants.

Construction of this large diked area creates the most logical and cost effective receptacle for impounding all other liquid wastes associated with the refining process. The red mud lake, as a recipient of the red mud and all other liquid wastes, offers a practicable and currently available technology to achieve the goals of the Act.

The nature of the other pollutants from a bauxite refinery, as described and discussed in Sections V and VI, are such that treatment is not a particularly viable option. These process wastes are characterized by the objectionable characteristics of alkalinity, acidity, and dissolved solids.

The first two characteristics can be neutralized, which transforms them into the third objectionable pollutant. Thus, the available facts lead to the conclusion that the optimum solution for treatment and control of all other pollutants from bauxite refining is impoundment in the red mud lake system. The technology is currently available and practicable.

It has generally been recognized by the bauxite refining industry that impoundment of the gangue from bauxite ore is feasible, and the refinery water circuit can operate either as a closed or nearly closed circuit. Accordingly, most plants currently impound at least the mud wastes, and, in many instances, other significant process waste streams.

There may be additional nonprocess streams, such as sanitary effluents and boiler and cooling tower blowdowns which must be disposed of. These lesser streams may or may not be included in the total impoundment site. In more arid climates, the tendency is to totally impound all streams; in high rainfall regions, the tendency is to discharge.

The parameters in the water circuit that inhibit adoption of total recycle of all streams (no discharge) are dissolved solids, and in some instances, heat. The precipitation step is the key to purity of alumina product and the efficiency of the operation. The effects of buildup of contaminants in process water do not appear to be completly defined or fully understood, and may well be significantly influenced by other variables. In any event, it appears that there is a tendency to bar contaminants whose behaviors are not understood, so that they will be discharged in preference to recycling to the process stream as a part of a total impoundment scheme.

The other problem is heat. The cooler the water the less treatment is needed and the easier it is to achieve a desired vacuum on a barometric condenser. Heat rejection may not be sufficient in a closed-loop lake system to provide for adequate cooling of barometric condenser effluents for reuse. Hence, some of these systems will use once-through cooling water when available in a satisfactory quantity and quality. Alternatives are cooling towers or much larger lakes.

State of the Art Control Technology

Waste Streams

The state of the art control technology can be best described in terms of the individual types of waste streams. The red mud stream must be impounded. Other alternatives are possible for the other waste streams. Due to the nature of the pollutants, primarily dissolved solids not readily precipitated, there are essentially no end-of-the-pipe pollution abatement schemes for these other bauxite process wastes. Some treatment technologies are described in the following paragraphs.

Red Mud.

The only practicable control technology for the enormous tonnages of muds produced by bauxite refineries each day is impoundment. Muds are impounded in large diked lakes, which may range in size from 40 ha (100 ac) to as much as 800 ha (2000 ac).

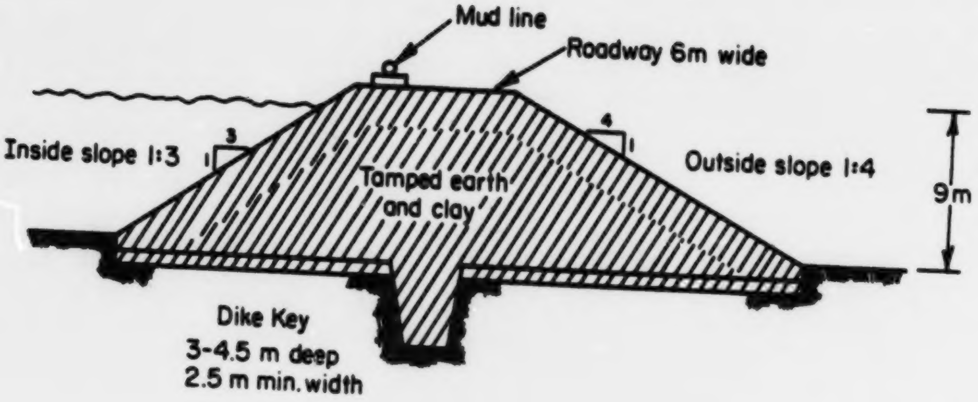
Two approaches are used for construction of mud lakes. The dikes are erected to their full height initially. The complete lake is available from the beginning, and additional dike construction is not required during the life of the lake. The construction of this kind of dike has been described by Rushing, (8) and is summarized below.

The installation described contained two mud lakes containing 4.8 and 3.3 square kilometers (1200 and 800 acres) and represents the largest such lakes in the bauxite refining industry. While the dike construction is generally typical, it was modified slightly because of some local considerations. The top layer of soil, about 25-30 cm (9-12 inches) was highly weathered, and was removed before construction of the dikes. The 25-30 cm below this was scarified and compacted to form the dike foundation. A trench was excavated around the entire perimeter of the lakes 3-4.5 meters (10-15 feet) deep and 2.5-3 meters (7.5-9 feet) wide. The trench was backfilled with clay and compacted in 15 cm (6 inch) layers as the dike was built. This feature helps to key the dike to minimize seepage of lake water. Details of the construction are shown in Figure 7. Embankments were laid out for a maximum height of 9 meters (30 feet) due to the somewhat poor bearing soils. Slopes of the dikes were lower (1:4 outside and 1:3 inside) than often used due apparently to local conditions. One other construction feature peculiar to the location was the facing of the dike nearest the bay with riprap to protect from hurricane tide and wave action. Pipe was laid on the top of the dikes with mechanical sections to allow for expansion movement and ease in breaking the sections apart to modify the pipe line. Several pipes also were routed to the center of the storage areas so that the mud could be distributed more evenly. The initial capital investment is higher for this method of dike construction, but maintenance and operating costs will be lower.

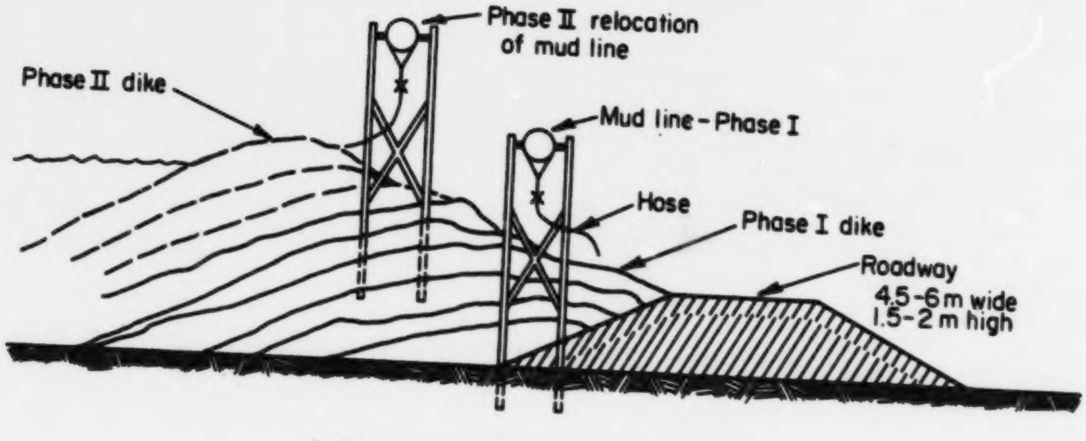
In the other, "low capital investment-high maintenance cost" approach, a low dike is initially built, which is continually raised as the lake fills. The construction of this type of dike is outlined schematically in Figure 7. Initially a low combination roadway-dike is constructed to a height of 1.2-1.8 meters (4-6 feet) and with a width of 4.5-5.3 meters (15-18 feet) from some stable sand-clay mixture. Along the inside perimeter, steel standards are erected, from which the mud pipe is suspended. The pipe has a tapered bottom shape, in which the coarser sands settle out. At intervals the tapered bottoms are valved; attached hoses are used to convey the sand to form sand dunes, with a gently sloping beach towards the inside of the lake. To avoid erosion of the beach, the main flow of mud is diverted well out into the lake. As the height of the dike approaches the original pipe line, a new set of standards is erected inside and the pipe lines relocated.

The success of this type of dike construction depends upon the existence of a coarse sand fraction in the red mud. Thus, this is practicable for Surinam bauxite, but less so for Jamaican bauxite. The net disposal costs appear to be comparable for the two approaches.

It is possible to raise the dike around a mud lake in stages by a variation of the above technique. With the usage of a drag line, previously settled and well-consolidated red mud can be dredged from the lake and cast on the bank to raise it in 2.5 meter (8-foot) increments. Slopes must be low and there is a significant


Mud line
Roadway 6m wide
3
1
Inside slope 1:3
4
1
Outside slope 1:4
Tamped earth and clay
9m
Dike Key
3-4.5 m deep
2.5 m min. width

a. Initial Full Dike Construction


Phase II relocation of mud line
Phase II dike
Mud line - Phase I
Hose
Phase I dike
Roadway
4.5-6 m wide
1.5-2 m high

b. Buildup Construction of Mud Lake Dike

Figure 7. Mud lake dike construction.

diversion of lake capacity to dikes. This technique can be applied even to Jamaican red mud, in spite of its nonsandy character.

Disposal of Jamaican red mud can pose special problems, resulting from its very small particle size and somewhat thixotropic character. Its settling properties are poor. For example, a maximum compaction of about 35 percent solids is possible if settling and compaction occur below a layer of water (8). If Jamaican mud can be spread in layers only inches deep rather than feet, and exposed to net evaporation conditions, it will dry satisfactorily. Once past a critical moisture content (i.e., the 60 percent solids range), the mud does not resuspend when wetted (8). However, adoption of this approach to the disposal of mud, like Jamaican red mud, depends upon the existence of a relatively arid climate, and the availability of large tracts of land for the disposal area. Where land is unavailable and rainfalls are high, this approach may not be practicable.

Another approach may be required in nonarid regions. One alternative, investigated at the U.S. Bureau of Mines by Good and Fursman (13), utilized centrifugal dewatering of Jamaican red mud. Results of this study indicated that the solids content could be increased to 40 percent. Approximately 40 percent of the slurry liquid was recovered as a clear effluent containing dissolved alumina and soda values for recycle to the plant. Economic analysis indicated that centrifugation and evaporation of the filtrate for recovery of the alumina and soda values was approximately a "break-even" operation. With this arrangement, a satisfactory consolidation and dewatering of Jamaican red mud is achieved, even in a region where the annual evaporation is less than the annual rainfall. The net positive water balance makes the management of the water circuit more difficult and may require increased evaporator capacity, but the circuit is controllable.

In all mud lake construction, care must be taken to insure that the bottom is as impervious as possible. Soil tests may be made to evaluate the bottom, and clay may be brought in for the bottom if an undesirable porosity is indicated. Depending on the structural characteristics of the underlying soil, the dike may also be keyed-in by excavating a trench along its center line before construction. Dikes were frequently built with a 1:1 slope; after some trouble with dike slippages and failures, a slope of 1:2 or less is now more common.

Dike heights will depend upon soil and mud characteristics. Heights of 6-9 meters (20-30 feet) are usual with good underlying soil conditions and a mud which sets up. Arkansas dikes can be as high as 18 meters (60 ft). Typically, a refinery initially constructs a mud lake of 20-40 ha (50-100 ac), surrounded by a dike on four sides. After this lake is filled, a new one is constructed adjacent to it. By using one side as a common dike, only three new sides need to be constructed, thus, reducing the capital investment.

Mud lakes are not single-purpose operations, nor is their cost entirely assignable to pollution control. They are, of course, primarily employed as receptacles for the waste mud residues. Secondary uses include cooling ponds and water reservoirs, as well as receptacles for other minor waste streams from the plant, such as boiler and cooling tower blowdowns and treated sanitary waste effluents. If soda concentrations are not excessively high, they can also serve to some extent as an additional mud washing stage. Thus, for the purpose of this report, the red mud lake may be considered as the major feature of the bauxite refinery. The intrinsic requirement for the disposal of the red mud residue from alumina plants has inherent effects on plant space requirements, plant site arrangement, and the initial design of the plant water system.

Spent Cleaning Acid. Spent cleaning acid from cleaning heat exchange surfaces, filter cloths, etc., consists of solutions containing high dissolved solids concentrations. One producer neutralizes the spent acid with mud before discharging to the river. Another producer is using an improved method, which involves the reaction of the spent cleaning acid with lime and forming insoluble calcium sulfate, which is then disposed of in the red mud lake. Several other producers achieve neutralization by conveying the spent acid to a red mud lake where it is neutralized by alkaline mud slurry. Some use an abandoned mud lake to eliminate any possibility of sulfate buildup in the red mud lake circuit; others use an active lake and find that enough sulfate is trapped by the settling mud to prevent sulfate buildup in the water circuit.

Using readily available technology, the spent cleaning acid could be neutralized to form an insoluble salt, evaporated to dryness, and disposed of to a landfill. If it were not for the existence of the alternative red mud lake "sink", this would no doubt constitute the recommended treatment technology.

Salts from Salting-Out Evaporator. Where dissolved impurities must be removed from the caustic liquor circuit of a bauxite refinery to prevent accumulation to levels causing interference with satisfactory operations, a salting-out evaporator is used on spent liquor returning to the digesters from the precipitators. By greatly concentrating the liquor, the solubilities of the contaminants are exceeded and they crystallize out. Principal components are sulfates, and sodium oxalate resulting from the traces of humic acid in the bauxite feed material.

One control technology is to dispose of the solid product to a landfill, with the waste being covered with soil to prevent leaching. Another technology, mentioned in an earlier section, avoids the problem by promoting the adsorption of contaminants upon the red mud prior to its separation from the pregnant bauxite slurry. However, this technology may be applicable only to Surinam bauxite.

Perhaps the simplest control technology, adopted by several producers, is the obvious one of disposal by impoundment in an abandoned red mud lake.

Barometric Condenser Cooling Water. This water comes under the heading of process water, because it comes into direct contact with process reactants. As noted earlier, very large quantities of water are used to provide the reduced pressure in the last stages of flash evaporators or multiple-effect evaporators. Because this condenser water is used in such high volume and the carry-over of alkali to it is small, it is sometimes discharged to surface waters without treatment. Two plants, (G and H), employ this procedure for discharge of all barometric condenser effluents. Another plant, (B), recycles the barometric condenser effluents from the green liquor flash evaporators to the process lake, but discharges the effluents from the barometric condensers, operating on the spent liquor multi-effect evaporators, to an adjacent bay. In all three cases, the receiving body of water is very large, with a large thermal capacity.

It must be recognized that waste heat, if not rejected to the water phase of the environment, must be rejected either to the earth or to atmosphere, and the latter is the more favored sink. The best technology available to dissipate heat to the atmosphere is evaporative cooling, and this technology is applied in several forms such as cooling ponds and cooling towers. In both cases, the water circuit is closed (except for blowdown) and the water is recycled for reuse. The simplest application is the use of a cooling pond or lake sufficiently large for the heat to dissipate to the atmosphere by evaporative cooling.

Cooling towers, both mechanical draft and natural convection, are also widely used, and would be considered as best practicable control technology currently available. Such technology does not require the large land area necessary for surface cooling systems, normally an advantage, but not necessarily one for a bauxite refinery, which requires a large pond area for other reasons. Thus, while cooling towers are normally economically competitive with evaporative cooling in ponds, towers may not be an individual option in selecting a cooling method.

When the barometric condensers are operated in closed circuit, as described above, the problem of potential alkaline carryover is taken care of, since any carryover is retained in the circuit.

Cooling Tower and Boiler Blowdown. Blowdown from a cooling tower associated with process barometric condensers constitutes a process waste. Since the contained pollutants are soluble salts, no simple and practicable precipitation technique is applicable. The blowdown could be evaporated to a solid state, suitable for landfill disposal. Reverse osmosis could be applied as a pretreatment to recover a pure water stream. Although the result would be discharge of pollutants, reverse osmosis would be significantly more expensive than direct disposal to a red mud lake. However, the best practicable control technology currently available consists of impoundment of this waste stream in an available red mud or process lake, which also achieves no discharge of pollutants to surface waters.

Blowdown from boilers and from associated cooling towers does not constitute a process waste stream. Effluent limitations guidelines and standards of performance for such streams will be developed in the near future.

Clean-Up Waste Streams. Hose-down and other clean-up waste streams are ubiquitous at a bauxite refinery. They contain suspended bauxite solids and pollutants found in bauxite liquor. These waste streams are low in alkalinity, but dilute. The best practicable control technology currently available is to recycle such wastes to the process, with the optimum point of recycle being the red mud lake. In a plant not operating on a water deficiency basis, economical usage of hose- down water will minimize the water management problems associated with excessive accumulation of water in the process water circuit.

Sanitary Wastes. Sanitary wastes are not considered as process wastes from bauxite refineries.

The application of the best practicable control technology currently available to process waste streams of the bauxite refining process is summarized in Table 12.

Industry Status and Plans.

The bauxite refining industry has begun to reduce the discharge of pollutants, and further reductions are planned. The present industry status and reported plans are summarized in Table 13. Exemplary plants, with no discharge of pollutants to surface waters, are plants C and E.

Total Impoundment Management.

The mud lake is the central item in any total impoundment management scheme. It is used for the alkaline mud stream and possibly for one or more of the other waste streams previously discussed. There is variability in the manner of handling the ancillary waste streams. They may also be disposed of in the mud lake or in other similar clear water or storm water reservoirs. The requirements for the recycling of the other streams are flexible, so that optional solutions are possible. This also includes the recycling of barometric condenser cooling water.

An important item in a total impoundment scheme is management of general aqueous wastes from the refinery. A well designed system will include concrete curbs around all process areas where spills or leaks of process solutions could occur, with the drains connected to a collection system. Ultimate disposal will be to the red mud lake or one of the other lakes in the total recycle circuit. Some trouble has been encountered in the past from

TABLE 12. SUMMARY OF EFFLUENT REDUCTIONS ACHIEVED FOR BAUXITE REFINERY PROCESS WASTES USING BEST PRACTICABLE TECHNOLOGY CURRENTLY AVAILABLE

Waste Stream	Parameters	Best Practicable(Level I) Technology Currently Available	Effluent Reduction Achieved
Red Mud	TSS, TDS, Alkalinity	Impound and recycles aqueous phase; concentrate if necessary (A,B,C,D,E,F,I)	No discharge
Spent Cleaning Acid	TDS, Sulfates, pH	Impound in red mud lake (B,C,D,E,F,)	No discharge
Salt slurry from salting-out evaporator	TDS, sulfates, alkalinity	Impound in red mud lake or landfill (C,E)	No discharge
Barometric condenser cooling water	TDS, Heat, alkalinity	Cool and recycle (1/2B,C,D,E,1/2F)	No discharge
Barometric condenser C.T. blowdown	TDS	Impound in red mud lake (B,C,D,E)	No discharge
"Hose-down" and clean-up streams	TSS, TDS, alkalinity	Recycle to process (Insufficient data)	No discharge

TABLE 13 WATER POLLUTION ABATEMENT STATUS AND PLANNED CHANGES (PROCESS AND NON-PROCESS WASTE STREAMS)

Plant	Waste Stream	Parameter	Disposition Present Status	 Planned Changes
A	Red mud	TSS, TDS, alkalinity	To red mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	Discharged to river	Neutralize with lime and to abandoned red mud lake
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	No salting-out evaporator	———
	Barometric condenser C.W.	TSD, heat	No barometric condenser used	———
	Boiler and C.T. blowdown	TDS	Boiler blowdown to river; no cooling tower	No change planned
	Compressor-after cooler	Heat	Once-through non-contact discharged to river	Install cooling tower and close cycle
	Hose-down	TDS, TSS, alkalinity	No data (return to circuit?)	No data (recycle?)
	Water softener sludge	TSS, alkalinity	No softener; potable water obtained from city	———
	Sanitary waste	BOD	Untreated; discharged to river	To be connected to city sewerage system

TABLE 13 WATER POLLUTION ABATEMENT STATUS AND PLANNED CHANGES
(PROCESS AND NON-PROCESS WASTE STREAMS)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
A	Red mud	TSS, TDS, alkalinity	To red mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	Discharged to river	Neutralize with lime and to abandoned red mud lake
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	No salting-out evaporator	———
	Barometric condenser C.W.	TSD, heat	No barometric condenser used	———
	Boiler and C.T. blowdown	TDS	Boiler blowdown to river; no cooling tower	No change planned
	Compressor-after cooler	Heat	Once-through non-contact discharged to river	Install cooling tower and close cycle
	Hose-down	TDS, TSS, alkalinity	No data (return to circuit?)	No data (recycle?)
	Water softener sludge	TSS, alkalinity	No softener; potable water obtained from city	———
	Sanitary waste	BOD	Untreated; discharged to river	To be connected to city sewerage system

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
B	Red mud	TSS, TDS, alkalinity	To red mud lake	No change planned
	Spent cleaning acid	TDS, sulfate, pH	To abandoned red mud lake	No change planned
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	No salting-out evaporator	———
	Barometric condenser C.W.	TDS, heat	Flash evaporator condensers C.W. to process lake; spent liquor evaporator condenser C.W. discharged to bay	No change planned
	Boiler and C.T. blowdown	TDS	Boiler blowdown to storm water lake; no cooling towers	No change planned ———
	Compressor after-cooler	Heat	To lake system; return to circuit	No change planned
	Hose-down	TSS, TDS, alkalinity	No data	To lake system (?)
	Sanitary wastes	BOD	Secondary treated effluent to lake system	No change planned
C	Red mud	TSS, TDS, alkalinity	To brown mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	Neutralized and to brown mud lake	No change planned
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	Evaporator to dryness and to covered landfill	No change planned
	Barometric condenser C.W.	TDS, heat	To clear lake; recycled to process	No change planned

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
C (cont'd.)				
	Boiler and C.T. blowdown	TDS	To lake system; recycled	No change planned
	Compressor after-cooler	Heat	To lake system; recycled	No change planned
	Hose-down	TDS, TSS, alkalinity	No date (to lake system ?)	To lake system (?)
	Sanitary waste	BOD	To lake system	No change planned
D	Red mud	TSS, TDS, alkalinity	To brown mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	To brown mud lake	No change planned
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	No data (not separated ?)	No data
	Barometric condenser C.W.	TDS, heat	Flash evaporator C.W. to mud lake; spent liquor evaporator C.W. to C.T. in closed circuit	No change planned
	Boiler and C.T. blowdown	TDS	Boiler blowdown to lake; no C.T. blowdown-intermittent cleanout	No change planned
	Compressor after-cooler	Heat	Once-through non-contact, discharged to river	No change planned
	Hose-down	TDS, alkalinity	No data	No data
	Sanitary wastes	BOD	To mud lake	No change planned

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
E	Red mud	TSS, TDS, alkalinity	To red mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	To red mud lake	No change planned
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	Calcined with soda ash and bauxite and leached	No change planned
	Barometric condenser C.W.	TDS, heat	To C.T. in closed circuit; recycled	No change planned
	Boiler and C.T. blow-down	TDS	To process water reservoir	No change planned
	Compressor after-cooler	Heat	To C.T. in closed circuit	No change planned
	Hose-down	TDS, alkalinity	No data	No data
	Sanitary wastes	BOD	Secondary treated effluent to process reservoir	No change planned
F	Red mud	TSS, TDS, alkalinity	To red mud lake	No change planned
	Spent cleaning acid	TDS, sulfates, pH	To red mud lake	No change planned
	Salts from evaporator	TDS, sulfates, alkalinity	No salting-out evaporator	No change planned
	Barometric condenser C.W.	TDS, heat	To red mud lake; recycled Summertime-use once-thru; to river	No change planned
	Boiler and C.T. blow-down	TDS	Discharged to river	No change planned

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
F (cont'd)	Compressor after-cooler	Heat	Once-through; non-contact, discharged to river	No change planned
	Hose-down	TDS, alkalinity	No data	No data
	Water softener sludge	TSS, alkalinity	Discharged to river	No change planned
	Sanitary wastes	BOD	Secondary treated effluent discharged to river	No change planned
G	Red mud	TSS, TDS, alkalinity	Discharged untreated to river	Solids to red mud lake; portion of supernate nautralized and discharged to river.
	Spent cleaning acid	TDS, sulfates, pH	No data (discharged to river ?)	No data
	Salts from evaporator	TDS, sulfates, alkalinity, oxalate	No salting-out evaporator	No change planned
	Barometric condenser C.W.	TDS, Heat	Once-through river water; discharged to river	Neutralize before discharged to river
	Compressor after-cooler	Heat	Once-through, non-contact, discharged to river	No change planned
	Hose-down	TDS, TSS, alkalinity,	No data	Recycled to process
	Sanitary wastes	BOD	Secondary treated effluent discharged to river	No change

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
H	Red mud	TSS, TDS, alkalinity	Discharged untreated to river	Solids to red mud lake; portion of supernate neutralized and discharged to river
	Spent cleaning acid	TDS, sulfates, pH	No data	No data
	Salts from evaporator	TDS, sulfates, alkalinity, oxolate	No salting-out evaporator	No change planned
	Barometric condense-C.W.	TDS, heat	Once-through river water; discharged to river	Neutralize before discharged to river
	Boiler and C.T. blowdown	TDS	Discharged to river	No change
	Compressor after-cooler	Heat	Once-through, non-contact, discharged to river	No change
	Hose-down	TDS, TSS, alkalinity	No data	Recycled to process
	Water softener sludge	TSS, alkalinity	Discharge to river	No change
	Sanitary wastes	BOD	Secondary treated effluent discharged to river	Improve plant

TABLE 13. (continued)

Plant	Waste Stream	Parameter	Disposition	
			Present Status	Planned Changes
I	Red mud	TSS, TDS, alkalinity	To red mud lake	No data
	Water softener sludge	TDS, TSS	Ocean water desalinated; reject stream returned to ocean	No data
	Spent cleaning acid			No data
	Salts from evaporator			
	Barometric condenser, C.W.			
	Boiler and C.T. blowdown			
	Compressor after-cooler			
	Hose-down			
	Sanitary wastes			

failure to install curbs, or from cracks and crevices in the concrete floor slab which permitted escape of alkaline process solutions. Most refineries have campaigns currently under way to eliminate these sources of effluents, and are expected to have them eliminated before July 1, 1977.

Another factor in a total impoundment scheme is whether the plant is located in an area of net rainfall or evaporation. As described in Section IV (Table 4), two refineries are located in areas where average annual evaporation substantially exceeds average annual rainfall. The other six refineries, located in the continental U.S., are in areas of net excess water accumulation, with annual averages ranging from about 10 to 40 cm (4-16 in). This complicates the water management scheme. It does not necessarily follow that a refinery, so located, must expend energy evaporating rainfall. The bauxite refining process intrinsically has a substantial negative water balance, which has to be supplied by either fresh water intake (purchased or otherwise acquired) in rainfall- deficient areas, or is supplied by the rainfall (in rainfall excess areas).

The negative refinery water balance arises from the fact that dried bauxite ore, is converted to anhydrous alumina product, with the water of hydration being eliminated in the alumina calcining kilns. The gangue material (red mud) is removed from the process as a wet mud containing at least 50% moisture. Much water is recovered as high-purity condensate from the flash tanks and added to the net positive rainfall accumulation, assuming a minimum red mud lake collection area. The generalized example described below is based on the following basic assumptions:

Plant capacity is 3,000 ton/day calcined alumina product, Jamaican bauxite, dried = negligible free water;

49% $Al_2O_3 \cdot 3H_2O$, 100% extraction efficiency (losses of Al to mud neglected);

1 ton (dry) mud/ton Al_2O_3 product;

CCD thickener and washer underflow = 20% solids;

10 lbs H_2O/lb, dry mud for washing; recycled water from mud lake, supplemented by makeup water;

Mud lake water: 5 g/l soda; 2.5 g/l aluminum;

1 lb H_2O/lb Al_2O3 final wash of product, using condensate or makeup water; eliminated in spent liquor evaporator;

Mud lake = 162 ha (400 ac);

Plant location gulf south, with net excess of rainfall over evaporation = 9 in/yr (e.g., New Orleans locations (Table 4)).

With the 3000 tons of recoverable alumina in the bauxite feed, there are 1590 ton/day of combined water of hydration. This is one of the key masses of water removed from the process; it passes up the stack to the atmosphere when the product is calcined.

As described in earlier sections, there are tremendous flows of water in internal circuits within the plant. Very large quantities of steam are used for heating, but nearly all of the contained heat is recovered and the condensate reused throughout the plant. Similarly, there are tremendous flows through the barometric condenser circuit. There are additions to and blowdowns from these circuits, but for this generalizied example, it can be assumed that they are in nominal balance.

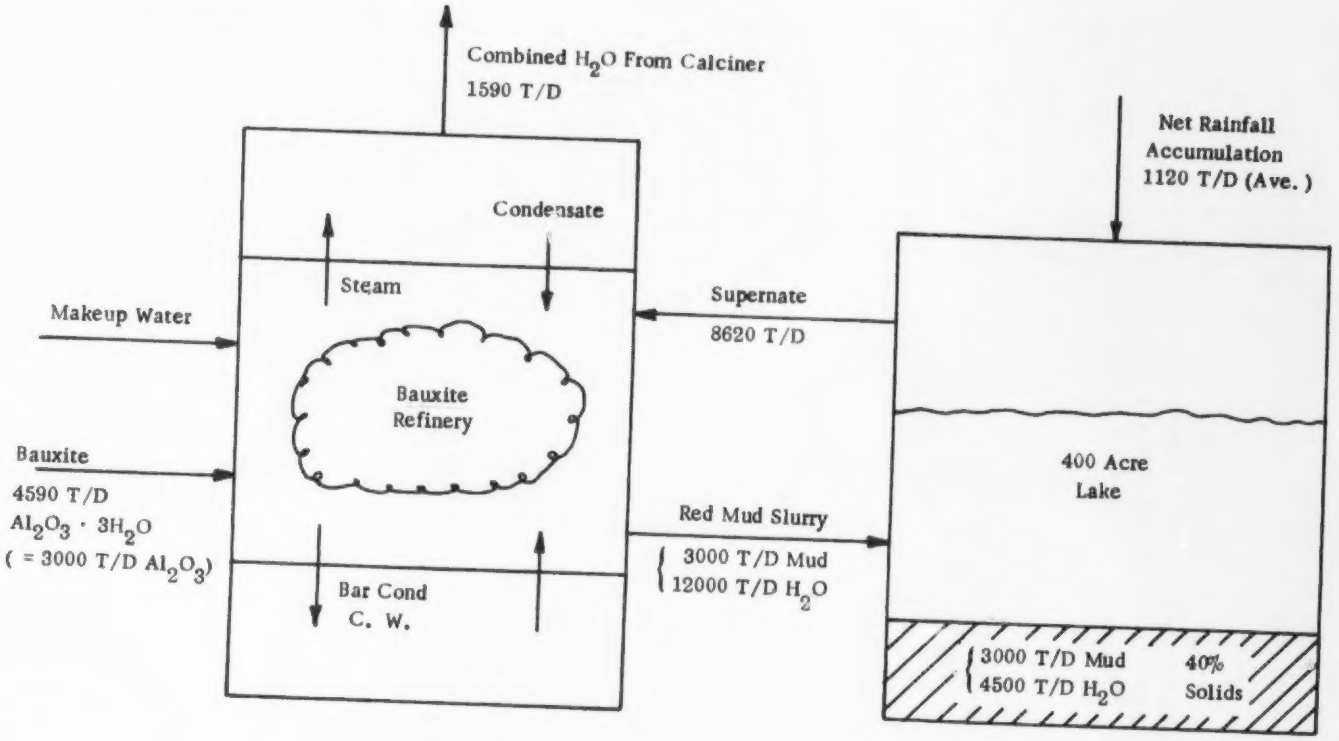
The other significant water withdrawal mechanism is the red mud. The underflow from the last washing thickener will approximate 15,000 ton/day, at 20% solids. Of the 12,000 tons of water going with 3,000 ton/day of mud to the red mud lake, only 7500 ton/day return to the process; the remaining 4,500 tons is tied up with the mud at the bottom of the lake. In total, these two mechanisms represent a removal of water from the hypothetical circuit of 6090 ton/day.

Rainfall is the only uncontrolled water input to the circuit. At the location of the example plant, the net average annual rainfall gain is 9-in/yr (Table 4). For the assumed 400-acre red mud lake, this represents 407,720 ton/yr, an average of approximately 1120 ton/day. Overall system deficiency is then 4970 ton/day, as illustrated by the schematic diagram in Figure 8.

This estimate should be regarded as an approximation, so that not all of the deficiency represents discretionary applications for the introduction of makeup water into the system. However, one comparable plant, operating with a closed circuit which is located in a more arid area of the Gulf Coast, has an actual water makeup requirement of this magnitude.

In spite of the approximate nature of the calculations of this generalized example, it is apparent that even in an area of net excess rainfall, it should not be necessary to distill rain in order to close the water circuit of a bauxite refinery. There is a sufficiently large difference between water inputs and outputs to the cycle, that with careful water circuit management, there should exist a net deficiency, which can be satisfied on a discretionary basis.

Closing the water circuit will tend to increase the buildup of soluble contaminants, making the incorporation of a salting-out evaporator into the spent liquor circuit necessary. However, there are also some monetary advantages which offset closing the circuit, such as elimination of losses of the soluble soda and aluminum associated with the red mud slurry. For the subject example, the 12,000 ton/day of red mud liquor leaving the plant


Combined H_2O From Calciner
1590 T/D
Net Rainfall
Accumulation
1120 T/D (Ave.)
Condensate
Steam
Makeup Water
Supernate
8620 T/D
Bauxite
Refinery
Bauxite
4590 T/D
$Al_2O_3 \cdot 3H_2O$
(= 3000 T/D Al_2O_3)
400 Acre
Lake
Red Mud Slurry
3000 T/D Mud
12000 T/D H_2O
Bar Cond
C. W.
3000 T/D Mud
4500 T/D H_2O
40%
Solids

WATER BALANCE

	IN
Rainfall, ave.	1120 T/D
TOTAL IN	1120

Deficiency = 4970

	OUT
Combined H_2O	1590 T/D
Settled Red Mud	4500
Total OUT	6090 T/D

Figure 8. Generalized diagram of basic water balance for a 3000 T/D bauxite refinery processing Jamaican bauxite.

carries approximately 60 ton/day of soda and 56 ton/day of alumina. Closing the circuit returns 7500 ton/day of supernatant to the plant, and recovers about 37.5 ton/day of soda and 35 ton/day of alumina.

In summary, current state of the art technology is to totally recycle all process waters and to impound all solid process wastes. Two plants are routinely doing this. Five others are totally impounding the red mud, as well as part or all of various other smaller streams.

Storm Water Management.

Most bauxite refineries have successfully solved the problem of providing for total impoundment of process wastes (i.e., no discharge of process waste water pollutants). The problem is defined and understood, and the technology is available to implement the effluent limitations.

Storm water management is not so clearly defined. The position generally held in the industry is that some quantities of storm water runoff from plant sites can be subjected to management controls, but that an upper limit needs to be established, above which, management (and collection) of storm water need not be attempted. Present technology (and that in planned installations) is based on designing a collection and storage system which will handle an average (not torrential) rainfall, but limitations on maximum flows are achieved by sizing pumps and piping in storm water systems or designing weirs at collection points which will divert flows above a predetermined maximum.

As evidenced by some of the rainfalls which can occur in the areas in which bauxite refineries are located (see Table 4), the total collection and retention of all rainfall may not be technically or economically practicable. The promulgated regulations provide provisions for the discharge of such rainfall.

SECTION VIII

COST, ENERGY, AND NONWATER QUALITY ASPECTS

Introduction

In this section, costs associated with the degree of effluent reduction that can be achieved by exemplary treatment methods are summarized. The nonwater quality aspects of solid waste disposal and the energy impact of the in-process control and waste treatment technologies are also discussed.

As noted in Section V, the pollutants found in waste water effluents from bauxite refining are characteristically either highly soluble, nonprecipitable, dissolved salts, or suspended solids (i.e., not amenable to end-of-pipe treatment technology). Thus, the only practicable treatment method for bauxite refining wastes is total impoundment, and the degree of effluent reduction achieved by impoundment is the total elimination of the discharge of process waste water pollutants to navigable waters.

Treatment and Control Costs

Although certain process credits undoubtedly derive from the quasi-washing stage, the costs of impoundment in the red mud lake and total recycle are considered wholly as pollutant control costs. Also, in the absence of a closed water cycle, additional sources of water intake would be required at some cost. However, the credits from the additional washing are difficult to estimate, and the water cost savings are highly location-dependent.

The capital cost of an impoundment and recycle system contains, in its simplest form the following major cost elements:

(a) Cost of land.
(b) Cost of construction of reservoir(s).
(c) Cost of equipment and facilities.

Such a system may serve as a depository for red mud tailings, a source of process water for the plant, and a cooling pond. In some instances the system installed may be large enough to satisfy the first two uses only. In this configuration, a cooling tower is an alternative for the cooling water supply.

The cost of land is a major consideration in any impoundment scheme. Estimated current land costs range from $200/ha ($500/ac) to $1200/ha ($3000/ac). However, most bauxite refineries have acquired the needed land years ago at substantially lower unit cost.

The cost of constructing the earthen dikes of a totally new mud lake reservoir are separable and identifiable, and are so reported. Even here, costs may not be entirely comparable, if one or more dikes of an existing lake is available.

The cost of equipment and facilities is difficult to reduce to a unit cost basis, since the major portion of these costs are associated with the construction of the first mud lake. Relatively minor costs may be incurred in relocating some of the equipment and facilities.

Thus, although the share elements, listed above, comprise the cost for total impoundment, available cost data are not so categorized. Not one producer supplied cost data by waste stream in a usable form; only the aggregate figure was supplied. Thus, only total capital costs are generally available, and the accuracy of these are suspect to some extent, where a timespan of 10-30 years may be involved. Nevertheless, within these limitations, capital costs reported are regarded as good order of magnitude values for past construction.

An additional factor requiring consideration in comparing reported costs is the type of bauxite to which the data apply. As indicated by Table 14, there can be a sixfold difference between mud production rates. However, total costs of disposal do not appear to be directly proportional to ton of mud/day, or size of plant. Reported costs for plants processing all three basic categories of bauxite ore are presented in Table 15. The dollar capital and annual operating costs are as reported. The unit capital costs are based on the (estimated) total alumina production represented by the capacity of the impoundment lakes. Unit operating costs were determined by apportioning reported operating cost expenditures over the annual alumina capacity of the plant.

Based on these data, impoundment of the processing wastes from Surinam bauxite requires a capital investment of $0.25 to $0.50/ton mud impounded and an operating cost of about $0.90-$1.30/ton of mud ($0.30 -$0.43/ton of alumina). For Jamaican ore, with its higher mud yield, capital costs are about $0.20/ton of mud and operating costs about $0.50/ton of alumina. Lowest costs, on a mud basis, are associated with mud-prolific Arkansas bauxite, of the order of $0.10 to 0.20/ton of mud capital costs and about $0.10 to 0.25/ton of mud operating costs. In spite of the approximate nature of the data, there is a surprisingly narrow range in waste disposal costs.

Estimated costs have also been supplied by the producer for Plants G and H. Neither of these plants currently has facilities for impounding red mud, although both are committed to doing so by order of a Federal consent decree (Plant G by July 1, 1975, and Plant H by July 1, 1974). In both cases, the impoundment will constitute a grass-roots installation, complicated by the fact that the whole configuration of the water circuits will have

TABLE 14. UNIT MUD PRODUCTION RATES FOR VARIOUS BAUXITES(a)

	Type of Bauxite Ore		
	Surinam	Jamaica	Arkansas
Tons mud/ton Al_2O_3 produced	0.33	1.0	2.0
Tons mud/1000 T/D Al_2O_3	330	1,000	2,000
Volume of mud, cu m/d(b)	410	1,248	2,496
Volume of mud, cu m/yr	147,600	449,280	994,560
Volume of mud, acre feet/yr	120	364	728

(a) Per 1000 metric tons of alumina production/day.

(b) Density of settled mud taken at 1600 kg/m^3 (100 lb/ft^3) and solids at 50%.

TABLE 15. SUMMARY OF WASTE DISPOSAL COST DATA(a)

Item	PLANT							
	A	C	D		E(c)	F		B
			Old Pond(b)	New Pond(b)		Old Pond(d)	New Pond	
Plant Capacity, metric tons/yr	820,000	325,000	755,000	755,000	1,300,000	560,000	560,000	1,150,000
Bauxite Type	Surinam	Arkansas	Arkansas	Arkansas	Jamaican	Surinam	Surinam	Jamaican
Mud Ratio(e)	0.33	2.0	2.0	2.0	1.0	0.33	0.33	1.0
Lake Capacity, metric tons dry mud	4.2×10^6	11.1×10^6	7.5×10^6	11.7×10^6	53.5×10^6(f)	3.0×10^6	1.7×10^6	--
Capital Cost, $	$1.13 × 10^6	0.9×10^6	0.69×10^6	2.06×10^6	9.52×10^6	1.26×10^6	0.82×10^6	--
Unit Capital Cost, $/metric ton mud	0.26	0.08	0.09	0.18	0.18	0.52	0.48	0.30
Annual Cost, $/yr	$264,000	75,600	373,000	--	571,000	166,000	--	--
Mud, metric tons/yr	205,000	660,000	1,520,000	--	1,160,000	187,000	--	--
Unit Annual Costs,								
$/metric ton mud	$1.29	0.11	0.24	--	0.49	0.89	--	0.35
$/metric ton alumina	0.43	0.22	0.48	--	0.49	0.30	--	--

Notes: (a) Mud basis, in 1971 dollars.
(b) Construction costs of old pond were expensed as incurred; new pond on capitalized basis.
(c) Exemplary plant, zero discharge of pollutants.
(d) Annual costs represent average costs for two old ponds.
(e) Lbs mud/lb of alumina produced.
(f) Very large lake; estimated capacity includes 20-year life still remaining.

to be reoriented toward impounding rather than toward direct discharge. Significant piping changes can be anticipated. The problem at Plant G is further complicated by the fact that land for impounding is not available adjacent to the plant, which is in a metropolitan area, and the red mud lake will be located 10 miles from the plant.

The estimated costs, as supplied by the producer, are summarized in Table 16. Estimated capital costs were not detailed so that it cannot be stated how costs are apportioned. Plant H is part of a large chemical complex and definitive data on division of effluent treatment costs between the bauxite refinery and the rest of the complex are not available. It is apparent, however, that these estimated costs differ from those reported by the rest of the industry by an order of magnitude.

It should be noted that the impoundment of red mud solids achieved by the proposed installation by plants G and H is not total. According to a letter to the U.S. Environmental Protection Agency by the producer (14), there will be approximately 72 million ton/day of suspended solids discharged.

Nonwater Quality Aspects

Energy Requirements

Pumping Costs. The energy consumed in pumping red mud and other effluents to an impoundment reservoir is comparable to that required to pump them to a discharge outfall in a navigable waterway, so the incremental energy usage is nominal. By the same reasoning, energy consumed in returning the supernatant from the lake to the plant is comparable to that required to pump fresh water to the process.

Evaporation Costs. Depending upon the location and overall design and management of the water circuit of a plant, the evaporation of excess water may be necessary to avoid discharge of effluents from the circuit. Thus, the expenditure of fossil fuel, in variable quantities, may be necessary; this presumes that the water to be evaporated will always be less than the quantity routinely evaporated to satisfy process requirements.

In support of the latter conclusion, the producer has estimated that 200 gal/min of rain water (1200 ton/day) might have to be evaporated if Plants G and H went to a closed circuit, with total recycle of process waters. However, it is estimated that water evaporated from the calcining kilns at these two plants is about 8680 ton/day, and the steam rate is about 400 ton/hr (9600 ton/day) for a total evaporative load of over 18,000 ton/day. If evaporation of rain water became necessary the evaporative load would be increased by only about 6 percent. (The water balance calculations presented in Section VII suggest that this should not occur). Also, discharge of excess rainwater has been addressed in the promulgated regulations.

TABLE 16. SUMMARY OF ESTIMATES OF FUTURE WASTE DISPOSAL COST DATA(a)

	Plant G(b)	Plant H(b)
Plant Capacity, metric tons/yr	1,100,000	865,000
Bauxite Type	Jamaican	Jamaican
Mud Ratio(c)	1.0	1.0
Lake Capacity, metric tons dry mud(d)	$8.25 - 11 \times 10^6$	$6.5 - 8.7 \times 10^6$
Capital Cost, $(e)	21,700,000	14,850,000
Unit Capital Cost, $/metric ton dry mud	1.97 - 2.63	1.70 - 2.28
Annual Cost/ $/yr(e)	5,487,000	4,391,000
Mud, metric tons/yr	1,100,000	865,000
Unit Annual Costs, $/metric ton mud	4.99	5.07
$/metric ton Al_2O_3	4.99	5.07

(a) In 1973-1974 dollars
(b) Plant does not now have a red mud lake
(c) Lbs mud/lb of alumina produced (approximate)
(d) Some uncertainty on life of pond, depending on efficiency of proposed dewatering system; estimated by producer at from 7.5-10 years
(e) Estimate supplied by producer

Solids Disposal

The volume of solid wastes (i.e., red mud) generated annually by the bauxite refining industry has been calculated to be 7,500,000 kkgs, equivalent to approximately 9.3 million cubic meters (12 million cubic yards) per year. This represents about 7600 ac ft, which, taken at an assumed mud lake-filled depth of 25 feet, means the diversion from other uses of an average of 300 ac of land per year.

SECTION IX

BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE --EFFLUENT LIMITATIONS GUIDELINES

Introduction

The effluent limitations which must be achieved by July 1, 1977, are to specify the degree of effluent reduction attainable through the application of the best practicable control technology currently available. This technology is based upon the average of the best existing performance by plants of various sizes, ages, and unit processes within the industrial category and/or subcategory. This average is not based upon a broad range of plants within the bauxite refining industry, but is based upon performance levels achieved by exemplary plants. Consideration must also be given to:

(a) The total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application.
(b) The size and age of equipment and facilities involved.
(c) The processes employed.
(d) The engineering aspects of the application of various types of control techniques.
(e) Process changes.
(f) Nonwater quality environmental impact (including energy requirements).

Best practicable control technology currently available not only emphasizes treatment facilities at the end of a manufacturing process, but includes the control technology within the process itself, when the latter is considered to be normal practice within an industry.

A further consideration is the degree of economic and engineering reliability which must be established for the technology to be currently available. As a result of demonstration projects, pilot plants and general use, there must exist a high degree of confidence in the engineering and economic practicability of the technology at the time of commencement of construction or installation of the control facilities.

Effluent Reduction Attainable Through The Application of Best Practicable Control Technology Currently Available

Based upon the information contained in Sections III through VIII of this report, a determination has been made that the degree of effluent reduction attainable through the application of the best

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practicable control technology currently available is no discharge of process waste water pollutants to navigable waters.

Identification of Best Practicable Control Technology Currently Available

Best practicable control technology currently available for the bauxite refining industry is recycle and reuse of process waters within the operation. To implement this requires:

(1) Acquisition of land, and construction, operation, and maintenance of dikes to provide one or more permanent lakes for ore tailings as well as reservoirs for the plant water circuit.
(2) Provision for means of cooling the effluent from barometric condensers for reuse in the plant, by the use of cooling towers or by use of the plant lake system.
(3) Retention of all general wastes (e.g., solution spills, floor and equipment washes, spent heat exchanger cleaning acid, acid filter, cloth washes, and other miscellaneous waste waters within the processing plant) by subsequent treatment and reuse or disposal on land. Maintenance of the integrity of floor slabs and curbs around plant areas will be a feature of such control measures.

There will be, in addition, some nonprocess waste streams (e.g., water softener backwash and boiler blowdown) for which control is more applicable than treatment. These wastes, relatively small in comparison with the main stream, can be readily incorporated into and included as part of the total impoundment system.

The technologies and levels of effluent reduction stated above have been demonstrated to the following degree by the existing plants in the industy:

(a) Two plants are known to be currently operating with no discharge of water.
(b) Four other plants have prepared or are implementing plans to achieve no discharge of process waste waters before the effective date of the effluent limitations.
(c) Two plants are currently discharging all wastes, but are implementing plans to impound red mud.

Rationale for the Selection of the Best Practicable Control Technology Currently Available

Age and Size of Equipment and Facilities

As set forth in previous sections of this report, the bauxite refining industry is characterized by:

(a) Very large plants, the smallest producing 900 kkgs(1000 tons)/day of alumina, and the largest producing 3600 kkg(4000 tons)/day.
(b) A plant age differential of 30 years.
(c) A commonality of process and equipment design arising from the universal use of the Bayer or combination process and that five of the nine existing plants were designed and built by one company.

These similarities, coupled with the similarities of waste water characteristics substantiate the best practicable control technology currently available to be total recycle.

Total Cost of Application in Relation to Effluent Reduction Benefits

Based upon the information contained in Section VIII, the industry as a whole would have to invest an estimated maximum of $42,000,000 to achieve the promulgated regulations. This amounts to approximately a 0.5 percent increase in projected capital investment for seven of the nine domestic refineries and 12.0 percent for the two remaining ones (Plants G and H).

Operating costs for the production of alumina from bauxite are estimated to be on the order of $55/kkg ($50/ton) of alumina. Increases in operating costs to achieve the limitations are estimated at $1,200,000 for seven of the nine U.S. refineries and $9,500,000 for the other two.

It is concluded that the benefits derived from the total elimination of process waste water pollutants to navigable waters outweigh the costs. Twenty-two percent of the plants are already achieving no discharge of process waste water pollutants. Fifty-five percent are achieving no discharge of red mud and are discharging only minor quantities of other process waters to surface waters; no discharge of pollutants from these plants can be readily achieved at moderate cost. Only two plants (22 percent) still discharge major process waters to surface waters.

Process Employed

There is only one product from U.S. bauxite refineries, purified alumina. The process chemistry is basically quite simple. The Bayer process or the combination process modification is universally used in the United States. Accordingly, the process flowsheets are essentially the same and the discharges are very similar. There is no evidence that operation of any current process or subprocess will substantially affect capabilities to implement the best practicable control technology currently available.

Engineering Aspects of Control Technique Applications

This level of technology is practicable because twenty-two percent of the plants in the industry are now achieving the effluent reductions set forth herein, and another fifty-five percent can achieve them with only minor process changes. The concepts are proven, available for implementation, and may be readily adopted through adaptation or modification of existing production facilities.

Process Changes

This technology is an integral part of the waste management program now being implemented within the industry. While it does require process changes at some plants, these changes are successfully practiced by other plants in the industry.

Nonwater Quality Environmental Impact

Total impoundment has a potential effect upon soil systems due to strong reliance upon the land for ultimate disposition of final effluents. Total annual land requirement for waste disposal is of the order of 120 ha (300 ac) per year. Impoundment areas must be impermeable to prevent the wastes from contaminating surface or subsurface waters. Air pollution could be a problem in arid locations from fugitive dust blowing from abandoned mud lakes. This has been controlled by keeping the surface of the ponds wetted.

SECTION X

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE -- EFFLUENT LIMITATIONS GUIDELINES

The best available technology economically achievable is identical to the best practicable control technology currently available. The corresponding effluent limitations are no discharge of process waste water pollutants to navigable waters.

SECTION XI

NEW SOURCE PERFORMANCE STANDARDS

The best available demonstrated control technology, processes, operating methods, or other alternatives is identical to the best practicable control technology currently available. The corresponding standard of performance is no discharge of process waste water pollutants to navigable waters.

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SECTION XII

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Mr. Marshall Dick, Office of Research and Development
Mr. John Ciancia, National Environmental Research Center, Edison
Mr. Lew Felleisen, Region III
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SECTION XIV

GLOSSARY

Acidity

The concentration of acid ions expressed as pH for a solution.

Act

The Federal Water Pollution Control Act Amendments of 1972.

Alkalinity

The alkali concentration or alkaline quality of an alkali-containing substance.

Alumina

Any of several forms of aluminum oxide, Al_2O_3, occuring naturally as corundum, in a hydrated form in bauxite, and with various impurities as ruby, sapphire, and emery.

Autoclave

A strong, pressurized, steam heated vessel, used to establish special conditions for chemical reaction, for sterilization, and for cooking.

Baghouse

Large chamber for holding bags used in the filtration of gases from a furnace, for the recovery of metal oxides and similar solids, suspended in the gases.

Barometric Condenser

An apparatus used to condense vapor, in which the vapors are condensed by direct contact with water in a vessel set sufficiently high so that the water drains from it in a barometric hot-leg into a sealed tank or hot-well.

Bayer Process

Process in which impure alumina in bauxite is dissolved in a hot, strong alkali solution, normally NaOH, to form sodium aluminate, which upon diluting and cooling the solution, hydrolyzes, forming a precipitate of pure aluminum hydroxide.

Bauxite

An impure mixture of earthy hydrous aluminum oxides and hydroxides that commonly contain similar compounds of iron, the principal ore of aluminum.

Best Available Technology Economically Achievable

Level of technology applicable to effluent limitations to be achieved by July 1, 1983, for industrial discharges to surface waters as defined by Section 301 (b) (1) (A) of the Act.

Best Practicable Control Technology Currently Available

Level of technology applicable to effluent limitations to be achieved by July 1, 1977, for industrial discharges to surface waters as defined by Section 301(b) (1) (A) of the Act.

Biochemical Oxygen Demand (BOD)

A measure of the oxygen demand in sewage and industrial wastes or in the stream, determined by chemical techniques. One technique (BOD_5) determines the 5-day oxygen demand.

Blowdown

A discharge from a system, designed to prevent a buildup of some material, as in a boiler to control dissolved solids.

Brown Mud

Thefinal solid waste remaining after the alumina is leached from the calcined red mud in the combination process.

Brown Mud Lake

The diked reservoir (tailings pond) used to impound brown mud.

Calcination

The roasting or burning of any substance to bring about physical or chemical changes; e.g., the conversion of lime rock to quicklime.

Capital Costs

Financial charges which are computed as the cost of capital times the capital expenditures for pollution control. The cost of capital is based upon a weighted average of the separate costs of debt and equity.

Category and Subcategory

Divisions of a particular industry which possess different traits which effect waste treatability and would require different effluent limitations.

Caustic Soda

Sodium hydroxide (NaOH)

Chemical Oxygen Demand (COD)

A measure of the oxygen demand equivalent of that portion of matter in a sample which is susceptible to oxidation by a strong chemical oxidant.

Clear Water Lake

Nominally the lake relatively free of alkalinity and other dissolved solids used as a fresh water reservoir for a bauxite refinery.

Combination Process

Variation of Bayer process used for high-silica ores, in which the red mud from the first stage Bayer process is calcined with soda ash and lime and leached to recover additional alumina.

Conductivity

A measure of the ability of water in conducting an electrical current. In practical terms, it is used for approximating the salinity or total dissolved solids content of water.

Continuous Countercurrent Decantation (CCD)

A continuous system of washing finely divided solids, such as red muds, to free them from liquids containing dissolved substances. In practice, the fresh wash water and the strong solids start at opposite ends and move countercurrently toward each other, so that the freshest water contacts the most thoroughly washed solids.

Depreciation

Accounting charges reflecting the deterioration of a capital asset over its useful life.

Digester

Pressure vessel or autoclave; vessels in which the alumina is dissolved from the bauxite.

Effluent

The waste water discharged from a point source to navigable waters.

Effluent Limitation

A maximum amount per unit of production of each specific constituent of the effluent that is subject to limitation in the discharge from a point source.

Electrostatic Precipitator

A gas cleaning device using the principle of placing an electrical charge on a solid particle which is then attracted to an oppositely-charged collector plate. The collector plates are intermittently rapped to discharge the collected dust into a hopper below.

Gangue

The worthless rock or other material in which valuable metals or minerals occur.

Green Liquor

The aluminum-bearing solution from the bauxite digesters before further processing.

Industrial Waste

All wastes streams within a plant. Included are contact and noncontact waters. Not included are wastes typically considered to be sanitary wastes.

Investment Costs

The capital expenditures required to bring the treatment or control technology into operation. These include the traditonal expenditures such as design, purchase of land and materials, site preparation, construction and installation, plus any additional expenses required to bring the technology into operation including expenditures to establish related necessary solid waste disposal.

mg/l

Milligrams per liter. Nearly equivalent to parts per million concentration.

New Source

Any building, structure, facility, or installation from which there is or may be a discharge of pollutants and whose construction is commenced after the publication of the proposed regulations.

New Source Performance Standards

Performance standards for the industry and applicable new sources as defined by Section 306 of the Act.

Operations and Maintenance

Costs required to operate and maintain pollution abatement equipment, such as labor, material, insurance, taxes, solid waste disposal, etc.

pH

A measure of the alkalinity or acidity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. A one unit change in pH indicates a tenfold change in acidity or alkalinity.

Plant Effluent or Discharge After Treatment

The volumes of waste water discharged from the industrial plant. In this definition, any waste treatment device (pond, trickling filter, etc.) is considered part of the industrial plant.

Pregnant Liquor

Solution containing the metal values prior to their removal and recovery.

Point Source

A single source of water discharge such as an individual plant.

Process Effluent or Discharge

The volume of water emerging from a particular process use in the plant.

Process Lake

Reservoir used for process water; often in closed circuit with part of process; not used for mud disposal.

Red Mud Lake

The diked reservoir used to impound red mud.

Secondary Treatment

Biological treatment provided beyond primary clarification.

Silicates

A chemical compound containing silicon, oxygen, and one or more metals.

Standard of Performance

A maximum weight discharged per unit of production for each constituent that is subject to limitation and applicable to new sources, as opposed to existing sources which are subject to effluent limitations.

Storm Water Lake

Reservoir for storage of storm water runoff collected from plant site; also, auxilary source of process water.

Surface Waters

Navigable waters. The waters of the United States including the territorial seas.

Thixotropic

Having the property exhibited by certain gels of liquefying when stirred or shaken and returning to the hardened state upon standing.

Total Suspended Solids (TSS)

Solids found in waste water or in the stream, which in most cases can be removed by filtration. The origin of suspended matter may be man-made or of natural sources, such as silt from erosion.

Unit Operation

A single, discrete process as part of an overall sequence, e.g., precipitation, settling, filtration.

TABLE 17.

CONVERSION TABLE

MULTIPLY (ENGLISH UNITS)		by		TO OBTAIN (METRIC UNITS)
ENGLISH UNIT	ABBREVIATION	CONVERSION	ABBREVIATION	METRIC UNIT
acre	ac	0.405	ha	hectares
acre - feet	ac ft	1233.5	cu m	cubic meters
British Thermal Unit	BTU	0.252	kg cal	kilogram - calories
British Thermal Unit/pound	BTU/lb	0.555	kg cal/kg	kilogram calories/kilogram
cubic feet/minute	cfm	0.028	cu m/min	cubic meters/minute
cubic feet/second	cfs	1.7	cu m/min	cubic meters/minute
cubic feet	cu ft	0.028	cu m	cubic meters
cubic feet	cu ft	28.32	l	liters
cubic inches	cu in	16.39	cu cm	cubic centimeters
degree Fahrenheit	F°	0.555(°F-32)[1]	°C	degree Centigrade
feet	ft	0.3048	m	meters
gallon	gal	3.785	l	liters
gallon/minute	gpm	0.0631	l/sec	liters/second
horsepower	hp	0.7457	kw	killowatts
inches	in	2.54	cm	centimeters
inches of mercury	in Hg	0.03342	atm	atmospheres
pounds	lb	0.454	kg	kilograms
million gallons/day	mgd	3,785	cu m/day	cubic meters/day
mile	mi	1.609	km	kilometer
pound/square inch (gauge)	psig	(0.06805 psig +1)[1]	atm	atmospheres (absolute)
square feet	sq ft	0.0929	sq m	square meters
square inches	sq in	6.452	sq cm	square centimeters
tons (short)	ton	0.907	kkg	metric tons (1000 kilograms
yard	yd	0.9144	m	meters

[1] Actual conversion, not a multiplier

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